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OCCURRENCE OF THE PLATINUM METALS IN SOUTH AFRICA.

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PART I.

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INTRODUCTION.

IT has been established during the past five years that South Africa has large reserves of the platinum metals, the principal

occurrences being in the Transvaal, that marvellous storehouse of mineral wealth. Previous to this period there had been two disastrous platinum booms based on alleged discoveries of the metal that were never substantiated; and desultory attempts had been made to work the Insizwa deposits in which metals of the platinum group occur in association with magmatic nickel-copper sulphides. It was only in 1921, however, that metals of this group began to figure for the first time in the already long list

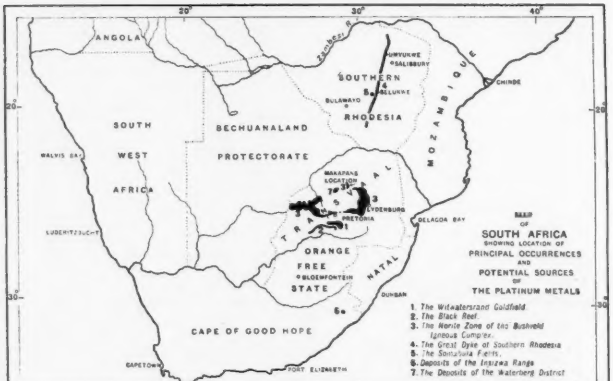


FIG. 1. Map of South Africa showing occurrences of platinum metals.

of the mineral products of the Union of South Africa. In that year the recovery of "osmiridium,"[1] initiated on a small scale at the Modderfontein Deep Levels Mine as early as June, 1919, was begun in earnest at several of the larger mines in the Far East Rand. The total production in 1921 was 509 ounces valued at £6,801. In 1924 this had grown to 5,763 ounces, of which were sold 4,107 ounces valued at £102,886. There is every prospect of a further substantial increase during the year 1925, when the value of the output sold should be in the neighborhood of £150,000.

[1] It will be shown presently that the "osmiridium" is in reality a concentrate containing several minerals.

TABLE I.

GEOLOGICAL FORMATIONS AND OCCURRENCES OF THE PLATINUM METALS.

Stratified Formations.		Igneous and Volcanic Activity.	Occurrences of Platinum Metals.
Cainozoic	Sands, river gravels, Marine inshore beds, lateritic deposits.	Formation of Salt Pan Volcano.	Alluvial deposits of Waterberg Dist. Eluvial and alluvial deposits of the Lydenburg, Potgietersrust and Rustenburg Districts.
Cretaceous	Sands, clays, Conglomerates, Marine limestones.	Extrusive limburgites of Limpopo Valley. Intrusive kimberlite and formation of pipes.	Lode deposits of Waterberg district. Occurrence in kimberlite.
Karroo System (Carboniferous-Triassic)	Sandstones, Shales, Mudstones, Tillite.	Intrusive dolerites and allied rocks. Extrusive basaltic lavas.	Occurrences in Karroo Dolerite and rocks allied to Karroo Dolerite. Occurrence in diamond-bearing conglomerates and gravels of Somabula Fields.
Cape System (Devonian)	Sandstones, Shales, Conglomerate, Tillite.		
Waterberg System	Sandstone, Quartzite, Conglomerate.	Intrusive nepheline and allied syenites. Extrusive basaltic lavas.	
Transvaal System (Pre-Cambrian ?)	Quartzites, shales, Dolomite, Conglomerate.	Intrusion of Bushveld Igneous Complex and of the Great Dyke of Southern Rhodesia. Extrusive acid and intermediate rocks. Granites of Cape Province. Extrusive basic rocks.	Occurrences in ultrabasic and basic rocks of Bushveld Igneous Complex and of the Great Dyke of Southern Rhodesia. Occurrences of iridosmine in the Black Reef.
Ventersdorp-Witwatersrand System (Pre-Cambrian)	Quartzite, Conglomerate, Shales, taconite.	Intrusive and extrusive basic rocks.	Occurrence of "osmiridium" in the gold-bearing conglomerates of the Witwatersrand System.
Swaziland System (Pre-Cambrian)	Schists, phyllites, limestones, marbles, conglomerates, taconite.	Intrusion at a later date of old Grey Granite and associated pegmatites. Intrusion of dolerite. Intrusion of ultrabasic rocks. Extrusion of basic and acid volcanic rocks.	Occurrences in Southern Rhodesia in serpentine and chromite. Occurrences(?) in other ultrabasic rocks of the Swaziland System. Occurrence in quartz vein in Old Granite.

Almost simultaneously with the beginning of the recovery on a big scale of "osmiridium" came the opening up of the remarkable platinum deposits in the Waterberg district of the Transvaal, followed in the latter part of 1924 by the very important discoveries in the Lydenburg district of the same province. More recently even more important discoveries have been recorded in other districts and there is every prospect of the Transvaal becoming ultimately the world's most important producer of the platinum metals.

As these metals occur in South Africa in the most diverse conditions and in rocks varying very widely in age, it will be useful at the outset, in order to render clearer their distribution in space and in the scale of geological time, to enumerate the several occurrences in relation to the principal geological formations of the country. This has been done in the following table in which the various groups of rocks are arranged in stratigraphical order, the oldest being at the bottom.

It is proposed to deal in ascending order with the actual and potential sources of supply.

OCCURRENCES IN ULTRABASIC ROCKS OF THE SWAZILAND SYSTEM.

These rocks include several types of serpentine and silicified serpentine,[2] talc schist, harzburgite, websterite, cortlandite, hornblende websterite, hornblendite, and enstatite hornblendite.[3] They are probably, as suggested by R. B. Young,[4] the source of the "osmiridium" in the conglomerates of the Witwatersrand System; the fact that the "osmiridium" is invariably accompanied by crystals and grains of chromite lending support to this view.

[2] Kynaston, H., *Trans. Geol. Soc. S. Africa*, 1907, p. 51; also Hall, A. L., "The Geology of the Barberton Mining District," Memoir No. 9, Geol. Surv. Union of S. Africa, pp. 195–209; and Maufe, H. B., "An Outline of the Geology of Southern Rhodesia," Short Report No. 17, Geol. Surv. of S. Rhodesia, p. 5.

[3] Hall, A. L., "Corundum in the Northern and Eastern Transvaal," Memoir No. 15, Geol. Surv. Un. of S. Africa, pp. 46–50.

[4] "The Banket," p. 40.

According to Thomas and MacAlister [5] some Southern Rhodesian serpentines have yielded chromite and picotite with traces of platinum. Zealley [6] is of opinion that the Selukwe chromite is referred to. An analysis made at the Imperial Institute of a sample of chromite from Selukwe showed 0.17 per cent. of copper and nickel oxides and a trace of platinum.[7]

No discoveries of platinum and allied metals have so far been made in the ancient ultrabasic rocks of the northern and eastern Transvaal, but encouraged by the success that has attended the efforts of platinum hunters in the Lydenburg and other districts, prospectors are beginning to devote attention to these rocks. It is quite possible that their efforts will bear fruit.

OCCURRENCE IN QUARTZ VEIN IN THE OLD GRANITE.

Small amounts of platinum have been found in a quartz-specularite vein on the farms Doorn River, No. 923, and Frischgewaagd, No. 201, situated 15 miles south of Marabastad in the Northern Transvaal. The country rock is old Grey Granite, but there is no means of fixing the age of the vein. There is thus complete uncertainty as to the date of the mineralization, and as to where this vein should be placed in the table. Metals of the platinum group are also said to occur with gold in the ore of the Old Sheba Queen and some of the adjoining mines in the Barberton District, Transvaal.

"OSMIRIDIUM" IN THE GOLD-BEARING CONGLOMERATES OF THE WITWATERSRAND SYSTEM.

The recovery of "osmiridium" has, as already remarked, become an important auxiliary to gold winning on the Witwatersrand. The output and sales for 1924 were made up as follows:

[5] "The Geology of Ore Deposits," London, 1909, p. 54.
[6] *Trans. Geol. Soc. S. Africa*, 1914, p. 64.
[7] *Bull. Imp. Inst.*, 1907, 5, p. 137.

Source of Production.	Output (Ounces).	Sales.	
		Ounces.	Sterling.
Witwatersrand Gold Mines	5,054.223	3,709.65	95,973
Heidelberg (Sub-Nigel Mine)	6.837	3.720	123
Recovered at Witwatersrand Corporation Smelting Works from old accumulated "Black Sands"	681.130	372.800	6,414
TOTALS	5,742.19	4,086.17	£102,510

The major portion of the output is derived from the conglomerates of the Main Reef Series, the Main Reef Leader, as developed on the Far East Rand, being the principal source of production. Notable amounts are, however, also being recovered from the Kimberley or Battery reef on the West Rand, and "osmiridium" has been proved to be present in conglomerate belonging to the Elsburg Series.

The existence of the metals of the platinum group in the conglomerates of the Witwatersrand System was first established by the late Wm. Bettel, who, in 1892 succeeded in extracting iridosmine (*sic*) and also platinum from "black sands" derived from the concentration of the banket of the "4-inch" Leader (Main Reef Series) of the New Rietfontein Mine.[8]

Subsequently, A. F. Crosse noted the presence of the platinum metals in the *banket* of the New Modderfontein and East Rand Proprietary Mines, and also in conglomerates belonging to the Elsburg Series at the Old Steyns Estate Mine[9]

The first actual description of iridosmine from the banket was given in 1907 by R. B. Young,[10] the material examined having been obtained from the New Rietfontein Mine. In 1912 C. B. Horwood published further particulars about the iridosmine of the New Rietfontein Mine.[11] He also called attention to the oc-

[8] Cf. *S. A. Min. Jour.*, 1906, Nov. 10.

[9] Cf. Horwood, C. B., "The Gold Deposits of the Rand," pp. 111–112.

[10] "Notes on the Auriferous Conglomerates of the Witwatersrand," *Trans. Geol. Soc. S. Africa*, Vol. X., 1907; also "The Banket," London, 1917, pp. 36–39.

[11] "Iridosmine from the New Rietfontein Mines, Analysis and Genesis," *Trans. Geol. Soc. S. Africa*, Vol. XV., pp. 52–63.

For more recent information on "Osmiridium" from the Witwatersrand Conglomerate see:

Thurlow, J. R., "Notes on Osmiridium," *Jour. Chem. Met. and Min. Soc. S. Africa*, 1922, pp. 209–211.

currence of metals of the platinum group in the Randfontein Mines, and predicted that minute amounts of these metals would be found throughout the conglomerates of the Main Reef Series. Subsequent investigations have confirmed this view. It was, however, only when amalgamation was abandoned in favor of preliminary concentration on corduroy and blankets that the recovery of these metals on a large scale became practicable. This change in the method of recovering the free gold present in the conglomerates was introduced in 1922. It has now been made on all the larger mines and "osmiridium" extraction has become an integral part of the dressing operations. What is actually recovered is a concentrate containing several distinct minerals, probably including native platinum. In addition to the platinum minerals, grains of gold are rarely absent, and sometimes quite abundant.

Distribution of the "Osmiridium."—As to the distribution of the "osmiridium" in the conglomerates of the Witwatersrand System, milling operations on a huge scale have definitely established that it is most abundant on the Far East Rand where the Main Reef Leader is being worked, less abundant on the West Rand where the Main Reef and South reefs are mined, and even less abundant on the Central Rand where all three beds of conglomerate are developed.[12] On the Far East Rand the principal producers in order of their productivity are the Government Gold Mining Areas, New Modderfontein, Modderfontein B, Brakpan and Modderfontein Deep Level Mines.

The distribution of "osiridium" in any particular area of gold-bearing conglomerate has been proved in several mines on the Far East Rand, like the gold, to go with the big pebbles, and its distribution in other respects also corresponds closely with

Rusden, H., and Henderson, J., "The Story of Osmiridium on the Rand. The Round Robin." Johannesburg, Jan., 1925.

Cooper, R. A., "Mineral Constituents of the Rand Concentrates," *Jour. Chem. Met. and Min. Soc. of S. Africa*, 1923, pp. 90–93.

Lawn, J. G., "Presidential Address to Geological Society of South Africa," *Proc. Geol. Soc. S. Africa*, pp. xix.-xxx.

12 Cf. Lawn, J. G., *loc. cit.*

that of the gold. Further, tests on the Modderfontein East and Modderfontein B Mines have proved that banket rich in gold contains much more "osmiridium" than banket poor in gold. According to the sedimentary theory of origin of the gold, which is now generally accepted, all this simply implies that the conditions favorable to the mechanical concentration of the gold were also favorable to the concentration of the "osmiridium," as would be expected from the close correspondence in their specific gravities.

It cannot be too strongly emphasized that even in the mines where it is relatively abundant the "osmiridium" constitutes only a vanishingly small proportion by weight of the *banket*. Thus on the Modderfontein B, which is richer in "osmiridium" than any other mine on the Witwatersrand, the recovery during 1924 was only 1 ounce per 1,212 tons of conglomerate milled. On the New Modderfontein Gold Mine it was 1 ounce per 1,567 tons, and on Government Gold Mining Areas 1 ounce per 1,973 tons. On the closely adjacent Van Ryn Deep Mine it was only about 1 ounce per 9,285 tons. What proportion of the platinum metals actually present in the conglomerates is recovered is not known. Judging by the percentage recovery of free gold which is very carefully calculated, it is improbable, however, that on an average it is less than 50 per cent. It is, no doubt, different in different mines.

The figures given above will make it clear that the recovery of the platinum metals except as a by-product would be quite impracticable. Even as a by-product their commercial recovery is possible only because amenable to concentration by simple and cheap methods.

Nature and Composition of the "Osmiridium."—The name iridosmine is used in a general way by mineralogists to designate the natural alloys of iridium and osmium. Two main varieties are distinguished, namely, iridosmium or nevyanskite which contains over 40 per cent. of iridium, and osmiridium or sisertskite which contains less than 40 per cent. of iridium. Both varieties are present in the Witwatersrand conglomerates, in which they

occur in six-sided crystals for the most part tabular, in cleavage flakes and in flattened oval-shaped and rounded grains. The crystals are made up of combinations of the basal pinacoid and rhombohedra or pyramids. Their edges as Young has pointed out, are invariably rounded. The crystals and grains of osmiridium, which greatly predominate, are of dark-gray color with a peculiar bronzy-red or bronzy-yellow sheen; their luster is dull. The iridosmium, on the other hand, is characterized by a tin-white color and splendent luster. Between these extremes are gray and grayish-white varieties. It is thus probable that quite a series of iridium-osmium alloys are represented.

The writer recently examined a sample of osmiridium concentrate from the Government Areas Mine. This was found to consist mainly of grains and crystals of osmiridium ranging from 0.04 to 0.16 mm. in diameter. They are accompanied by flat platy crystals of iridosmium up to 0.19 mm. across, and by cleavage flakes of that mineral. In addition to what may be grains of a light-colored variety of iridosmine, there are present spherical and oval shaped metallic particles of grayish-white color. These may be worn grains of native platinum, but the writer did not succeed definitely in determining them as they proved to be resistant even to hot *aqua regia*. Apart from them there are to be seen small rough-looking rounded grains of a dark-colored unidentified metallic mineral, grains and octahedral crystals of chromite, crystals of zircon, and numerous small oval-shaped grains of gold. One such, with a maximum diameter of .14 mm., was found to enclose completely except on one side, where it projects, a crystal of iridosmine .06 mm. in diameter. As it is generally agreed that the gold in the Witwatersrand Conglomerates has undergone solution and reprecipitation this interesting and unique specimen has no special genetic significance.

Chemical Composition.—Chemical analyses of a number of typical samples of the "osmiridium" concentrate are given in the following table. The first three were placed at the writer's disposal by Mr. F. W. Watson of the Rand Mines Laboratory.

In addition to the metals named traces of palladium are also sometimes found.

ANALYSES OF "OSMIRIDIUM" CONCENTRATE.

Name of Mine.	I. Modderfontein B.	II. City Deep.	III. Knight Central and Wolhuter (mixed).	IV. Government Areas.
Ir.....	28.12	29.02	34.71	35.78
Os.....	32.72	37.11	39.26	39.71
Ru.....	15.12	12.45	11.28	9.60
Pt.....	11.44	8.41	7.00	6.12
Rh.....	0.46	0.19	0.22	.16
Au.....	0.27	4.10[13]	0.07	.39
Totals.....	88.13	91.28	92.54	91.76

The balance is insoluble gangue.

I.–III.....Analyzed by D. C. Griffith & Co., London.
IV.....Analysis quoted by J. G. Lawn, *loc. cit.*

[13] This is evidently gold left in the concentrate by accident or oversight.

It will be noted that these analyses disclose the presence of considerable amounts of ruthenium and platinum. It is not known in what state or combination these metals are present, but they are known to be especially abundant in the finer part of the concentrate. F. W. Watson, the leading authority on the subject, is emphatic in asserting that they are not contained in the "osmiridium," as they can be extracted from the concentrate without decomposing the crystals and grains of that mineral. But he has never succeeded in separating the platinum mechanically. The present writer is of opinion that the ruthenium is contained in the unidentified dark-colored mineral already referred to as forming rough-looking rounded grains. This, however, is little better than a guess. It is evident from what has been said that much mineralogical work remains to be done on the Rand "osmiridium." A fascinating field for research here awaits some mineral chemist with a sound working knowledge of the metals of the platinum group.

Genesis of the "Osmiridium."—The osmiridium and allied

minerals are without doubt of contemporaneous deposition with the conglomerates. As Young [14] has pointed out, there are all gradations from crystals with slightly worn edges to completely waterworn grains. It is also quite clear that unlike the gold these minerals did not undergo solution and recrystallization, but are in the condition in which they were originally deposited.

While there cannot as yet be said to be any general agreement as to the precise manner in which the gold-bearing conglomerates were laid down, geologists are unanimous in their support of Mellor's view that the materials of which they are composed were brought down from the northwest or north-northwest by one or more rivers that discharged into a great delta on the site of the present Witwatersrand. These rivers evidently carried to their ultimate resting place the minute crystals and grains of "osmiridium" and related minerals that are now, after having for years baffled the ingenuity of the metallurgical engineer, being successfully extracted from the *banket*.

Available Reserves in the Witwatersrand Conglomerates.

The total quantity of "osmiridium" locked up in the conglomerates of the Witwatersrand System must be large. The available reserve, however, is limited, because, as we have seen, it will never be possible to recover it except as a by-product of gold mining, and the very considerable amounts that have in the past found their way into the vast sand and slime dumps are also irrecoverable.

The output will thus necessarily be strictly proportioned to the output of gold, and, in particular, to that of the mines working on the more productive section of the Far East Rand, where the bulk of the "osmiridium" comes from. It is likely, as previously stated, that for the present year the value of the output will be in the neighborhood of £150,000. Provided that the prices of iridium and osmium are maintained at their present level, it will probably remain at roughly that figure for years to come, as there is no prospect in the near future either of any

[14] "The Banket," *loc. cit.*, p. 39.

marked increase or decrease in gold production on the Far East Rand. The output will eventually decrease *pari passu* with the decline in the gold production of that area.

IRIDOSMINE IN THE BLACK REEF.

The basal member of the Transvaal System, the Black Reef conglomerate, carries profitable amounts of gold in places in irregular shoots and patches. That the gold is accompanied by metals of the platinum group was established in the Klerksdorp District as early as 1888. More recently the conglomerate has been found in certain areas to carry notable amounts of iridosmine. Thus, at the old Vesta Mine to the southwest of Johannesburg, and in the Machavie Mine in the Klerksdorp district.

Assay values as high as 20 dwt. per ton have been reported from the footwall of the " reef " in these mines, but it difficult to get reliable information. Active prospecting for iridosmine is at present in progress at a number of mines and properties on the Black Reef. The only actual production is by a small worker washing the dumps of the old Orion and Minerva mines on the Black Reef near Natal Spruit south of Johannesburg. The output from this source amounted in 1924 to 21.31 ounces, valued at £376.

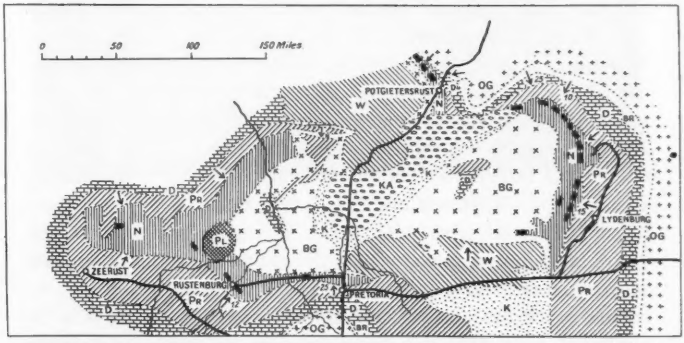
OCCURRENCES IN AND CONNECTED WITH THE NORITE ZONE OF THE BUSHVELD IGNEOUS COMPLEX.

As a preliminary to the description of these, incomparably the world's greatest primary platinum deposits, it will be useful to say a few words about the Bushveld Igneous Complex. This is a vast composite body of plutonic and volcanic rocks [15] of pre-Waterberg age, occupying an area of over 15,000 square miles of the central part of the Transvaal. It consists in its outer or lower portion of norite and allied basic and ultrabasic rocks, in its inner or upper portion of red granite, granophyre and felsite.

[15] Cf. Daly, R. A., and Molengraaff, G. A. F., *Jour. Geol.*, 1924, pp. 1–35, who give a full bibliography.

The norite, with which we are more particularly concerned, forms a great basin-shaped sheet or lopolith some three miles in thickness. This over the greater part of the immense area which it occupies was intruded into the uppermost part of the Pretoria Series of the Transvaal System. In the Potgietersrust district, however, it cuts diagonally downward across the rocks of the Transvaal System until it rests directly on the Old Granite.

GEOLOGICAL SKETCH MAP
SHOWING POSITION OF THE
PLATINUM DEPOSITS IN THE NORITE ZONE OF THE BUSHVELD IGNEOUS COMPLEX.



OG—Old Granite; BR—Black Reef; D—Dolomite; Pr—Pretoria Series; W—Waterberg System; N—Norite; BG—Bushveld Granite; Pl—Pilandsberg Complex; K—Karroo System; KA—Bushveld Amygdaloid; ▬ Platinum.

FIG. 2. Geological sketch map showing platinum deposits of the Bushveld Igneous Complex.

In some areas the norite zone is fairly uniform throughout. In others its lower portion has been differentiated to a marvellous degree, being made up of lenses, lenticular sheets and more continuous bodies of the most diverse rocks.[15a] The following varieties are represented: bronzitite, chromite rock or chromitite, dunites, harzburgite, wehrlites, ilmenite wehrlite, bastite serpen-

15a The basal portion of the lopolith is everywhere formed of chilled and hybrid marginal rock types. Where there has been marked differentiation the *differentiated zone*, as the writer has elsewhere termed it, follows directly on this basal zone.

tine, silicified serpentine, hornblende rock, anorthositic norite and pure anorthosite, to mention only some of the more important. Cutting these rocks are dikes of graphic granite, pegmatite, and other types of granitic rock. The salic minerals composing them, as the writer has shown elsewhere,[16] are of the nature of released minerals derived from material left over in the complex process of crystallization differentiation.

The upper part of the great norite sheet in contradistinction to the lower is throughout of a much more uniform character, being occupied mainly by spotted norite except in its uppermost portion where there are big stratiform segregations of titaniferous magnetite associated with layers of anorthosite.[17] All the important occurrences of platinum so far found in the norite zone are confined to parts of the lopolith exhibiting in their lower portions extreme heterogeneity as regards the rocks composing them. It is thus apparent at the outset that pronounced differentiation is one of the essential conditions for the magmatic concentration of platinum. This conclusion is amply borne out by such detailed studies as have been made of the individual deposits. There are, however, areas where, notwithstanding that the norite zone presents striking evidence of profound magma splitting, no notable concentrations of platinum have been found. It is to be concluded from this that some portions of the parent norite magma were much richer in platinum than others.

In passing, brief reference may be made to another striking feature of the norite zone that has a direct bearing on the subject under discussion. This relates to the remarkable manner in which the rocks composing it are pseudostratified. They behave throughout like well bedded sediments, their dip and strike, which often exhibit the utmost regularity over considerable distances, conforming to those of the underlying rocks of the Pretoria Series. As a consequence of this regular pseudobedding it is generally possible to distinguish fairly definite zones and horizons in the great sheet, some of which can be followed for miles.

[16] Wagner, P. A., Memoir No. 21, Geol. Surv. Union of S. Africa, p. 87.
[17] Cf. Hall, A. L., Rep. Geol. Surv. Transvaal, 1909, pp. 70–72.

The Platinum Occurrences.—These are very numerous and spread over an enormous area, the distance between the extreme points at which platinum has been found, measured along the

FIG. 3. Pseudo-Statification in Anorthositic Norite overlying Merensky Platinum horizon on Farm Driekop, No. 170, Lydenburg District, Transvaal.

periphery of the norite zone, being nearly 400 miles. The deposits are as varied as they are numerous.

They may be classified as in Table II.,[18] page 124.

The writer has given a fairly complete account of the Bushveld deposits in the paper quoted and in an earlier description of the Lydenburg Platinum Fields.[19] What follows must be regarded as a summary of these papers.

Hortonolite Dunite Deposits.

In these, platinum occurs as a primary constituent of iron-rich dunite composed essentially of the variety of olivine known as

[18] Cf. Wagner, P. A., "Notes on the Platinum Deposits of the Bushveld Igneous Complex," *Trans. Geol. Soc. S. Africa*, November, 1925.

[19] Cf. Wagner, P. A., "The Platinum Deposits in the Western Part of the Lydenburg District, Transvaal," *South African Journal of Industries*, February, 1925.

TABLE II.

CLASSIFICATION OF THE PLATINUM DEPOSITS OF THE NORITE ZONE OF THE BUSHVELD IGNEOUS COMPLEX.

- *A*. Deposits formed by direct segregation from the parent norite magma.
  - III. Deposits in which platinum is associated with magmatic nickel-copper-iron sulphides in small specks.
  - II. Chromitite deposits.
  - I. Hortonolite-Dunite deposits.
    - *a*. In upper part of norite zone.
      - (7) Steelpoort Park type in which ore-bearer is a medium-grained feldspar-rich spotted norite.
      - (6) Minsk Claims type, Lydenburg District, in which ore-bearer is a coarse-grained feldspar-rich diallage norite.
    - *b*. In lower part of norite zone.
      - (5) Miscellaneous deposits in acid quartz-bearing differentiates of the norite magma.
      - (4) Merensky Horizon type occurring above and below the main horizon in the Lydenburg District.
      - (3a) Merensky Horizon type as developed in the Lydenburg, Pietersburg, Potgietersrust, Pretoria and Rustenburg districts; the ore-bearer being pseudo-porphyritic pyroxenitic diallage norite.
      - (3) Sandsloot-Zwartfontein type (Potgietersrust District)—apparently a special phase of the deposits of the Merensky Horizon type. Ore-bearer is a coarse-grained feldspathic bronzitite, generally containing notable amounts of hornblende, which merges into coarse-grained, pegmatitic hornblende norite.
      - (2) Tweefontein type (Potgietersrust District) in which the ore-bearer is a fine-grained pyroxenitic diallage norite, merging into coarse-grained feldspathic bronzitite and bronzitite.
      - (1) Vlakfontein type (Rustenburg District) in which the ore-bearer is bronzitite.

B. Contact-metasomatic deposits in altered dolomite and sheared banded ironstone directly underlying platinum-bearing norite and pyroxenite.

hortonolite, which is accompanied by subordinate amounts of phlogopite, hornblende, diallage, chromite, and titaniferous magnetite. The dunite has the distinction of being the heaviest rock composed of silicates so far described (Sp. Gr. 3.752), and the richest in ferrous iron. For this unique rock the name hortonolite dunite (Onverwacht type) has been proposed elsewhere.[20] It is just possible, however, as we shall learn, that it is of pegmatitic nature and that hortonolite-dunite-pegmatite would be a more accurate designation. The petrography of the dunite has been fully dealt with by Wagner and Mellor and an analysis of the rock is given in Column 1 of Table III.

Over 60 separate occurrences of hortonolite dunite have been found so far in the lower part of the norite zone the majority of them being barren of platinum or containing only traces of that metal. There are two main types of occurrence. In one the hortonolite-dunite forms pipe- or parsnip-shaped segregations and veins in olivine dunite. In the other it forms segregations in diallage pegmatite and allied rock types. The important deposits on Onverwacht and Mooihoek, to be referred to below, belong to the former category, while apparently all the platinum-poor or barren occurrences in the Lydenburg and Rustenburg Districts belong to the latter. In both types of occurrence the rock enclosing the hortonolite-dunite exhibits a transgressive relation to the more normal rocks of the norite zone.

Only three of the dunite deposits have so far proved to be worthy of exploitation; they are situated on the farms Onverwacht, No. 330, Mooihoek, No. 147, and Driekop, No. 170, in the western part of the Lydenburg District; all three occurrences lying between the two main horizons on which chromitite is found in this area. A fourth occurrence, which is giving promising platinum values, has recently been found on the farm Mooihoek, No. 147, in close proximity to the one above referred to. It is too early, however, to express a definite opinion on it.

The most important occurrence is that on the farm Onverwacht, No. 330. This measures 60 by 60 feet on the surface, the out-

[20] Wagner, P. A., and Mellor, E. T., "On Platinum-bearing Hortonolite-Dunite of the Lydenburg District, Transvaal," *Trans. Geol. Soc. S. Africa*, 1925, pp. 1–18.

B. Contact-metasomatic deposits in altered dolomite and sheared banded ironstone directly underlying platinum-bearing norite and pyroxenite.

crop being roughly circular. It has now been followed to a depth of over 200 feet. It is becoming gradually smaller at depth and, as already indicated, has apparently the shape of a parsnip.

The platinum content of the hortonolite dunite varies from 2 to 137.8 dwts. per short ton, equivalent to 0.0234 per cent. At the surface the average platinum content was about 20 dwts. per ton; at the 100-ft. level 18 dwts.; at the 150-ft. level 6.8 dwts., and at the 200-ft. level 4 dwts. This indicates a progressive impoverishment downward. Recently, however, good values have been obtained below the 200-ft. level and it is thus impossible at present to make any generalization. Very high platinum values were obtained immediately below water level, 170 feet. Whether this is a coincidence or whether there has actually been supergene platinum enrichment remains to be ascertained.

The occurrence on Mooihoek, No. 147, has also been proved to be parsnip-shaped segregation in serpentinized olivine-dunite. It has been explored to a depth of 137 feet and carries from a fraction of a pennyweight to 30 dwts. of platinum per ton. It is paralleled by veins of hortonolite dunite arranged at right angles to the pseudostratification of the rocks of the norite zone.

The Platinum.—Platinum occurs in the dunite in well-shaped crystals of cubic and more rarely octahedral habit, and in irregular grains and nuggety forms up to 4 mm. across. The metal is sometimes visible to the naked eye.

The platinum is alloyed with iron and subordinate amounts of osmium, iridium, rhodium, and palladium. A representative sample from the Onverwacht occurrence was analyzed by Messrs. F. W. Watson and R. A. Cooper with the following result:

	Per Cent.
Pt	84.00
Os, Ir	2.30
Rh	0.20
Pd	0.30
Cu	Trace
Fe	12.80
Total	99.60

This proves it to be almost identical in composition with the platinum of some of the principal Uralian deposits.

An examination of polished sections of the platinum shows that it is a homogeneous solid solution of platinum and iron through which are scattered minute subhedral crystals of iridosmine or aggregates of such crystals.[21]

In the other type of hortonolite-dunite occurrence that rock forms segregations and schlieren in irregular bodies of diallagite or diallage-hortonolite-ilmenite rock, which by their very coarse texture and their relations to the surrounding rocks prove that they are of the nature of pegmatites. The dunite which they enclose is thus itself clearly of pegmatitic origin. The platinum-bearing hortonolite dunite of the Lydenburg District is identical in every way with that under discussion. It is not improbable, therefore, for this and reasons elsewhere given, that it also is of a pegmatitic nature. This would explain many of the peculiarities of the deposits. It should be stated that there are no objections to the pegmatite hypothesis on theoretical grounds as it is known from the occurrence of fayalite in lithophyses in rhyolite and obsidian,[22] and in pegmatite [23] that iron-rich olivine can crystallize under pneumatolytic conditions.[24]

As to why some occurrences of hortonolite dunite should be rich in platinum while the majority are very poor or barren, the writer has shown in the paper already quoted that extreme basicity of the residual magma fraction from which they crystallized, and the presence of fluorine, were probably essential to the formation of rich deposits.

Chromitite Deposits.

Segregations of chromitite, as the writer has elsewhere remarked,[25] are confined to those portions of the lower part of the

[21] Stanley, G. H., and Wagner, P. A., "A Note on the Microstructure of Transvaal Platinum," *Jour. Chem. Met. Min. Soc. S. Africa*, March, 1925.

[22] Iddings, J. P., and Penfield, S. L., *Am. Jour. Sci.*, vol. XXX., 1885, p. 58.

[23] Penfield, S. L., and Forbes, E. H., *Z. f. Krystallographie*, 1896, p. 143.

[24] Rosenbuch, H., "Mikroskopische Physiographie," I., 2, p. 158.

[25] Wagner, P. A., "The Chromite of the Bushveld Igneous Complex." *S. A. Jour. Sci.*, 1923, pp. 223–235.

norite zone exhibiting pronounced differentiation. The chromite rock or chromitite forms lenses and seams ranging in length from 2 feet to 1,000 feet, and in thickness from an inch to 6 feet. They conform to the pseudostratification, the dip varying from 8 to 25 degrees.

In the Lydenburg District the principal deposits occur on two fairly well-defined horizons, separated by a vertical interval of from 75 to 500 feet. In the Rustenburg District there are in places three chromite horizons. The chromite rock usually presents a curiously mottled appearance. This is due to its structure which is best described as pseudo-porphyritic poikilitic. It consists of a black ground, composed of small interlocking chromite crystals, through which are scattered oval-shaped grains of bronzite up to 1.5 cm. in length spotted with minute chadacrysts of chromite. Such pseudo-phenocrysts often make up the bulk of the rock. In addition to the chromite, or, more correctly chrompicotite, subordinate amounts of calcic felspar are usually present. The rock contains from 28 to 48 per cent. of chromic oxide. It is being quarried at several localities for its chromium content.

It has been known for years [26] that the chromitite carries small amounts of platinum and fairly high assays were occasionally recorded. Speaking generally, however, it was found impossible to repeat these assays, and up to six months ago no occurrence had been located that gave consistent platinum values over even a short distance. Recently, however, there have been opened up on the Upper chromite horizon in the extreme northern part of the Lydenburg District, between latitude S. 24° 15′ and latitude S. 24° 30′ two considerable stretches of chromitite, which wherever sampled have given assays of from 1.5 to 12 dwts. of platinum per ton. They are situated on the farms Zeekoegat, No. 312, and Forest Hill, No. 342. The writer recently had an opportunity of examining the deposit on Forest Hill. This lies about 1 mile to the east, and roughly 1,200 feet vertically below

[26] Hall, A. L., and Humphrey, W. A., *Trans. Geol. Soc. S. Africa*, 1908, pp. 69–77.

the Merensky platinum horizon. The strike is magnetic north and south and the dip of the chromitite and associated rocks 13° east. The deposit has been opened up at intervals of 150 feet in five workings. The chromitite forms a seam varying in thickness from 2 feet to 3 ft. 6 in.

Samples of the rock taken by the engineers of the Transvaal Estates and Development Company, Limited, from the M. 3 and M. 4 Workings respectively, returned up to 8.5 and 11.9 dwts. of platinum per ton. A sample over three feet in the M. 3 Working, taken by Mr. C. J. Grobler, Assistant Inspector of Mines, gave 2 pennyweights of platinum per ton.

The chromitite "reef" on Zeekoegat Farm is even more promising. It is said to average about 7 dwts. of platinum over considerable distances. It was recently sampled at two points by Mr. J. E. Vaughan, Inspector of Mines, Pretoria. One of the samples, which were assayed in the Government Chemical Laboratory, Johannesburg, returned 11.5 dwts. of platinum metals over 42 inches, and the other 5.5 dwts. over 18 inches, the chromitite body not being properly exposed at this point.

Good platinum values have also been obtained recently from the Upper chromite horizon on the farm Paschas Kraal No. 126, which lies almost midway below Zeekoegat, No. 312, and Forest Hill, No. 342.

This suggests the possibility of there being other stretches of platinum-rich chromitite within the limits stated.

Platinum Associated with Magmatic Nickel-copper Iron Sulphides.

Magmatic Nickel Deposits on the Farm Vlakfontein No. 902, Rustenburg District.—These deposits, described in detail elsewhere,[27] are isolated masses of irregular shape composed partly of disseminated, partly of poikilitic, and partly of massive or solid sulphide ore. The principal ore minerals are pyrrhotite, pentlandite, and chalcopyrite. At and immediately below water-

[27] Cf. Wagner, P. A., "On Magmatic Nickel Deposits of the Bushveld Igneous Complex," Memoir No. 21, Geol. Survey Union of S. Africa.

level the pyrrhotite has been largely replaced by marcasite. The ores have been carefully tested for platinum metals, but these have so far only been proved to be present in traces. Where sufficient amounts were found to enable a definite test to be made, it was established by Messrs. F. W. Watson and R. A. Cooper that palladium and not platinum is the metal present. Platinum has so far only been found in the oxidized ore of the No. 2 Working, where it is present in combination with arsenic in the rare mineral sperrylite. Judging by such tests as have been made, that mineral is very sparse and erratic in its distribution even in the ore of this particular occurrence. As a potential source of platinum the Vlakfontein deposits thus appear to be relatively unimportant.

The country rock of the deposits, as already indicated, is bronzitite. This encloses lenses and sheets of harzburgite and light-colored anorthositic norite streaked with bands of anorthosite. The writer was led to conclude from his mapping that there was some genetic relation between the distribution of the nickel deposits and that of the lenses and bands of anorthositic norite. This view has received support from what we now know of the sulphidic platinum deposits of the Lydenburg and Potgietersrust districts. To these full reference is made in a subsequent section of the present paper.

Deposits on the Farm Goudini No. 177, Marico District.—Associated with much the same types of rock as the Vlakfontein deposits is the platinum occurrence recently opened on the farm Goudini, No. 177, situated in the Marico District, some 30 miles north-northeast of Zeerust. Here promising platinum assays have been obtained from coarse-grained bronzitite composed of dull green prismatic individuals of that mineral up to 1.5 centimeters in length.

The bronzitite is impregnated with secondary limonite probably derived from the oxidation of pyrrhotite, and is interspersed with small patches of pale blue green chrysocolla derived from chalcopyrite. The results of the opening up of this deposit will be awaited with interest.

Deposits of the Merensky Horizon Type.

Lydenburg and Pietersburg Districts.—Here belong the great deposits on the Main or Merensky Horizon on which sufficient work has now been done to justify the statement that, if the demand for and the price of platinum should ever warrant it, a score of big low-grade mines could be started immediately. The platinum-bearer, as previously indicated, is a remarkably persistent sheet or layer of dark-colored pseudoporphyritic pyroxenitic diallage-norite. The rock shows considerable variation as regards the relative proportions of felspar and pyroxene present. For much of it the designation felspathic pyroxenite would be more appropriate. The sheet lies from 800 to 1,400 feet above the Upper Chromite horizon and conforms strictly to the general pseudostratification. The strike in conformity with that of the rocks of the norite zone varies from E.–W., through N.W–S.E. to N. and S. The dip, which is to the south-southwest or west, varies from 6 degrees to 25 degrees, the average being about 13 degrees. The pyroxenitic norite is invariably underlain and overlain by light-colored spotted anorthosite or anorthositic norites which clearly stand in a complementary relationship to the platinum-bearer. The ore horizon ranges in thickness from 3 to 30 feet. It has now been located at intervals from the farm Doornvlei, No. 612, adjoining M'Phatleles Location in the Pietersburg district to the farm Sterkfontein, No. 221, in the southern part of the Lydenburg District, a distance of roughly 90 miles. From the Olifants River to the farm De Goede Verwachting, No. 313, it can be followed almost without a break. There are places where the platinum-bearing layer gives out, but it generally re-appears within a short distance on the same horizon. Between the southern part of De Goede Verwachting, No. 313, and the southern part of Tweefontein, No. 35, the rocks of the norite zone are considerably disturbed. The normal westerly dip is often seen to be reversed and great bodies of sedimentary rock have been floated up from the floor of the great intrusion. In this belt of disturbance the Merensky Horizon appears to be

missing, there being a gap of some 8 miles. From the northern part of Dwarsrivier, No. 86, however, which adjoins Tweefontein, the outcrop is practically continuous all the way to Sterkfontein, No. 121.

Numerous incline shafts have been put down on the Merensky Horizon, and a number of adits have been driven into it. It has also been intersected by boreholes and shafts at distances of up to 2,000 feet from the outcrop. Sulphides appear everywhere at depths ranging from 50 to 200 feet on the incline, which, according to the dip, would correspond with vertical depths of from 9 to 50 feet. The contact between the oxidized and sulphidic ore is, as a rule, very irregular. There is no appreciable difference between the platinum content of the two types of ore, proving that there has been no secondary enrichment at water-level.

The sulphides form small interestitial grains ranging from .2 mm. up to .8 cm., and exceptionally up to 2 cm. across. They consist of irregular intergrowths of pyrrhotite, pentlandite, and chalcopyrite, the three minerals being named in order of their abundance. The textural relations of the composite sulphide grains to the pyroxenes and other silicates present point to their being indigenous to the platinum-bearing norite. Definite proof, however, that they are and that they were not, as Tolman and Rogers [28] have suggested, in writing of magmatic sulphide deposits generally, "introduced at a late magmatic stage as a result of mineralizers," is afforded by the broader geological relations between the sulphidic norite and the associated anorthositic rocks, particularly, when as on St. Edmonds, No. 220, and Kalkfontein, No. 22, the ore-bearer forms isolated lenses completely enclosed in spotted or mottled anorthosite. It is inconceivable that vagrant mineralizing solutions could have picked out such lenses and impregnated them with sulphides, and this without leaving any trace of their passage in the surrounding rocks which are perfectly fresh and unaltered.

The Platinum.—Platinum is present in the sulphide ore in the

[28] "A Study of the Magmatic Sulphide Ores," *Leland Stanford Junior University Publications*, 1916, p. 22.

metallic state and also possibly as sperrylite, as the ore has been proved to contain traces of arsenic. The platinum is contained in the sulphides and where careful tests have been made, as for instance on St. Edmonds, No. 220, it has been established that there is a definite relation between the platinum content of the ore and the percentage of sulphides present. Where the ore horizon is thin, it generally carries platinum throughout: where thick, platinum is generally concentrated in its upper portion. This part of the deposit has been found to average between 2 and 3 dwts. per short ton over miles. In certain areas higher average values have been obtained. Thus a 900-ft. stretch on Onverwacht, No. 330, averaged 5.5 dwts. over 50 inches, and on St. Edmonds, No. 220, and Der Brochen, No. 226, considerable sectors have been found to average between 4 and 5 dwts. per ton over widths of from 24 to 48 inches. On Dwarsrivier, No. 86, where the outcrop has been carefully sampled over a distance of 8,000 yards, the average value throughout is about 3 dwts. over 48 inches.

The platinum obtained by panning specimens of the norite is on the whole much finer than that of the dunites. It occurs in small grains and crystals of yellowish-white and white color. No complete analysis of the platinum of this horizon is as yet available. Such analyses as have been made indicate, however, that it contains up to 20 per cent. palladium. It is accompanied by subordinate amounts of gold, there being on an average one part of gold to every 20 parts of platinum. Exceptionally, however, as on Paschas Kraal, No. 126, the ratio is much higher.

An analysis of the oxidized ore is given in Table III.

Pretoria District.—Ore of the Merensky Horizon type indistinguishable from that found in the Lydenburg District has been opened up about 1,000 yards south of the Rustenburg Railway on the farm Elandsfontein, No. 374, situated 22 miles W.N.W. of Pretoria. The outcrop has been traced for a distance of several miles. The ore-body is not fully exposed, but the thickness appears to be at least 20 feet. The platinum content ranges up to 2.5 dwts. per ton. The ore-body is associated with the same

types of rock as are found above and below the Merensky Horizon in the Lydenburg District. The hanging-wall is formed of light-colored anorthositic norite merging upward into mottled anorthosite, and the footwall appears to be formed by spotted anorthosite. The deposit is at present being opened up.

Rustenburg District.—Early this last December ore of the Merensky Horizon type has been opened up on the farms Turffontein, No. 293, and Waterval, No. 544, to the north-northwest of Rustenburg, and on Kroondal, No. 177 to the southeast of that town. On Kroondal the platinum deposit lies from 800 to 1,000 yards—measured horizontally—above the uppermost of the three chromite horizons present in this part of the norite zone The platinum-bearing layer is overlain and underlain by spotted anorthosite.

In one of the prospecting trenches on Vaalkop, No. 77, the platinum-bearing part of the deposit was found to average from 4 to 5.30 dwts. over widths of from 40 to 64 inches. In the main working on Waterval, No. 544, the upper three feet of the "reef" assayed 7.7 dwts., and the lower two feet, 4.7 dwts. of platinum per short ton.

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REPLACEMENT IN THE TIN-BEARING VEINS OF CARACOLES, BOLIVIA.

WALDEMAR LINDGREN.

INTRODUCTION.

THE Caracoles district is situated in the central part of Bolivia, about 50 miles southeast of La Paz, in the part of the Cordillera Real which is usually called Quimsa Cruz.[1] The development of the tin-bearing veins of Caracoles is a recent event, since the properties were acquired about 1918 by the Guggenheim interests. It is not intended to present a full account of the mode of occurrence of the ore deposits in this district. This paper only aims to portray the processes of replacement by which the veins have been formed and outline the chemical changes which have taken place in the country rock. The observations on which the article is based were made in the summer of 1921.

GEOLOGY.

The main backbone of the Quimsa Cruz Range extends for 30 kilometers from the high peaks northeast of Araca to Monte Blanco. The wagon road from Eucaliptus, a station on the Antofagasta-La Paz railroad, to Caracoles crosses the range at Apacheta Tres Cruces (elevation 15,500 feet), southeast of Monte Blanco. South of this pass rise the last of the snowy peaks, Santa Vela Cruz, and beyond this the range rapidly falls off to lower elevations. The highest peaks of the Quimsa Cruz Range have not been measured, but they attain elevations from 18,000 to 20,000 feet. Viewed from the high plateau on the west, the range does not appear imposing, but just across the pass the observer is confronted by the deeply incised extremely steep-walled canyons of the eastern drainage and by desolate scenic effects rivalling the wildest part of the Cordillera of South America.

[1] See Fig. 54, ECONOMIC GEOLOGY, vol. 15, 1920, p. 469.

Paleozoic, probably Devonian, black clay slates, with some quartzite beds, predominate in Quimsa Cruz; they generally dip at steep angles and are highly compressed. Only at the granite contacts are they strongly metamorphosed.

In the central part of the range granite appears, forming a mass about 25 kilometers long and from 2 to 8 kilometers in width from east to west. It probably does not connect with the granite area north of La Paz River, which is known to occur in the Illimani block of the Cordillera Real. The rock, normally white, appears gray or black in outcrops, the dark color being caused by a thin growth of lichen. The slates appear to dip away from the central granite, so that the mass is somewhat similar to a laccolith—that is, a body intruded into and bulging up the sediments. The contacts show clearly the intrusive character of the granitic rock.

TIN DEPOSITS OF QUIMSA CRUZ.

The veins at Caracoles are contained in granite, but though their development is recent, tin mining has long been carried on in Quimsa Cruz, mainly, however, in the surrounding slates. On the north is the Araca Mine, long known for the beautiful cassiterite crystals there found; at Chojnacota (Green Lake) on the west; at Monte Blanco and Vela Cruz on the south. Of these deposits the Araca is easily the most famous.

The occurrence of tin deposits at Caracoles has been known for a number of years, but difficulty of access undoubtedly delayed their development, now undertaken by the Guggenheim interests.

Several of the deposits of Quimsa Cruz have been described. The Concordia Mine, at Vela Cruz, has been investigated by Rumbold;[1] also the Monte Blanco deposits. Both are in slate and quartzite and show strong tourmalinization. The Araca Mine was discussed by G. Steinmann;[2] this is also in the slate area to the west of the granite, but the tourmaline, if present, is not markedly developed. Finally, F. L. Hess[3] has described the

[1] Rumbold, W. R., Economic Geology, vol. 4, 1909, pp. 321–364.

[2] Steinmann, G., *Zeitschrift d. d. Geol. Gesell.*, vol. 59, Protocol, 1907, pp. 7–9.

[3] Hess, F. L., *Eng. and Min. Jour.-Press*, Sept. 24, 1921.

tin and tungsten veins of Pacuni, which are in granite near the contact and only a few miles from Caracoles. Armas[4] also mentions the mines of Araca, Concordia, and Monte Blanco.

In all these deposits silver is practically absent, except in traces, and tourmaline is usually present.

W. M. Davy mentions one deposit from the Caracoles district, the San Enrique.[5] The specimens examined were, however, not fully representative, as they came from the upper oxidized zone.

Almost all of these writers emphasize the replacement of granite, slate, or quartzite, and it is evident that they consider the veins as in part of metasomatic origin. Several of them also, like Rumbold, Armas and Davy, and Hess, mention the prevalence of chlorite in the altered country rock and, less commonly, in the vein itself.

It is evident, therefore, that the Quimsa Cruz region contains an abundance of cassiterite veins both in slate and granite, and that the veins in slate, generally speaking, form an aureole about the central granitic mass. All of them appear to belong to the high-temperature type, or, in other words, to the hypothermal veins. It looks on the face of it as if they were largely deposited by emanations from intrusive masses of granite.

THE CARACOLES VEINS.

The veins of Caracoles outcrop in a wild glaciated district of granite cliffs and canyons, of small dismal lakes and green glaciers. The elevations range from 15,000 feet up to the eternal snows beginning at 18,000 feet above the sea.

The veins strike generally N. 30° E. or N. 75° E., the dip being to the northwest at from 43° to 85°. The width averages a few feet and the ore is fairly sharply separated from the altered country rock. However, the veins are almost wholly replacements along narrow fissures, the ore itself containing much black or brown felted tourmaline, with quartz, honey brown or yellow cassiterite, some chlorite, and a little pyrite and sphalerite. Apa-

[4] Armas, M., *Annales des Mines*, 10th Ser., vol. 20, 1911, pp. 149–230.

[5] Davy, W. M., Economic Geology, vol. 15, 1920, pp. 463–496.

The norm shows that the rock is a toscanose and that it is related to the quartz monzonites of Leadville and Telluride in Colorado (98, 115 Tosc. in Washington's list), also to rocks from the Boulder batholith, Montana. According to the norm orthoclase and plagioclase are in about equal amounts. Actually some potassium goes to biotite and there is more plagioclase than orthoclase.

I think all this shows clearly that this is not a granite, but an intermediate rock characteristic of the Cordilleran petrographic region. This makes it extremely probable that the intrusion is of late Mesozoic or Tertiary age. The majority of the geologists, who have described the granites of the Cordillera Real, have assigned an earlier age[6] to them.

Petrography of the Altered Rocks.—The altered rocks are so similar that they may be described together. They are dull greenish gray with visible granitic texture and contain quartz, orthoclase, chlorite, sericite, tourmaline, siderite, and apatite.

Under the microscope an inherited granular structure is observed, more or less obscured by an actual development of fibrous sericite and chlorite; of residual minerals, quartz is most prominent, with some orthoclase. The plagioclase has disappeared. Sericite in fine fibers is pseudomorphic after plagioclase and biotite and disseminated through orthoclase. Chlorite, of a variety rich in iron, is abundant, shows light gray interference colors, and is in large part pseudomorphic after biotite, but also disseminated through orthoclase; in part as veinlets of radial structure. Index of refraction averages 1.638; small axial angle, optically negative (confirmative determination by Professor E. S. Larsen); a little siderite occurs in chloritized biotite. Prisms of apatite and rutile and a few radiating fibers of tourmaline complete the list of minerals. Pyrite and magnetite are absent.

Two samples were analyzed; the result is given in the following table:

[6] Douglas, J. A., *Quart. Jour. Geol. Soc.* (London), vol. 70, 1914, Pt. 1, pp. 1–53. Dr. Douglas refers to the age as "post-Devonian and pre-Jurassic."

ANALYSES OF ALTERED WALL ROCKS.

Helen Vassar, Analyst.

	16.C.	2.C.	17.C.
SiO_2	63.82	67.61	65.39
Al_2O_3	16.03	17.30	16.15
Fe_2O_3	None	None	1.08
FeO	8.79	5.60	3.29
MgO	2.49	1.35	1.87
CaO	.37	.38	3.07
Na_2O	None	None	2.28
K_2O	3.74	4.82	5.35
H_2O+	4.77 *	3.66 *	1.13 *
H_2O-	Not det.	Not det.	.11
TiO_2	Not det.	Not det.	.48
P_2O_5	.36	Not det.	.40
	100.37	100.72	100.60

* Ignition.

16.C. Altered quartz monzonite directly adjoining ore, Llamero tunnel, Caracoles. Sp.gr. 2.81.

2.C. Altered quartz monzonite directly adjoining ore, Carmen Rosa vein, Caracoles. Sp.gr. 2.77.

17.C. Fresh quartz monzonite adjoining 16.C. Sp.gr. 2.70.
Trace of tin and very small quantity of Mn in 16.C. and 2.C.

It is obvious that without knowledge of the composition of the chlorite exact calculations of the mineralogical composition can not be made, and in these samples the chlorite can not easily be separated. Determinations on well-crystallized chlorite from the Argentine Mine—really part of the Caracoles district—show that the mineral is poor in magnesia and rich in iron, as indeed indicated by the index of refraction.

For preliminary purposes I have assumed a composition of the chlorite like aphrosiderite as follows: SiO_2, 26.08; Al_2O_3, 20.27; FeO, 32.91; MgO, 10; H_2O, 10.06. Then the calculations proceeds as follows: Estimating first the FeO and CO_2 for a small quantity of siderite, the rest of the FeO and MgO is used to determine the amount of chlorite. The remainder of "ignition" goes to sericite (SiO_2, 47.50; Al_2O_3, 35.16; K_2O, 10.0; H_2O, 4.0). The remainder of K_2O goes to orthoclase. Free silica from total silica by subtracting amounts assigned to chlorite, sericite, and orthoclase.

On this basis we obtain:

	16.C.	2.C.
Quartz	40.4	41.0
Sericite	24.5	36.0
Chlorite	22.5	13.0
Orthoclase	8.6	9.0
Apatite	1.0	not det.
Siderite	3.0	1.0
Tourmaline	0.6	.5
	100.6	100.5

If we assume that there has been no marked change of volume during the alteration, the material added and subtracted can be estimated. The direct comparison of the analyses 16.C. and 17.C. gives a pretty correct idea of the changes, as the specific gravity of the sample is approximately the same.

For more specific results we may multiply the two analyses in grams per 100 by the specific gravity, 2.70 for 17.C. and 2.81 for 16.C., to obtain grams per 100 cc.; by comparison we obtain gains or losses during alteration in grams per 100 cc.

TABLE SHOWING GRAMS PER 100 CUBIC CENTIMETERS AND GAINS AND LOSSES.

	17.C.	16.C.	Gains (+) or Losses (−) during Alteration.
SiO_2	176.6	179.3	+2.7
AlO_{23}	43.6	45.0	+1.4
Fe_2O_3	2.9	None	−2.9
FeO	8.9	24.7	+15.8
MgO	5.0	7.0	+2.0
CaO	8.3	1.0	−7.3
Na_2O	6.2	None	−6.2
K_2O	14.5	10.5	−4.0
Ignition	3.1	13.4	+10.3
(CO_2+H_2O)			
TiO_2	1.1		
P_2O_5	1.3	1.0	−0.3
	271.5	281.9	

This would indicate gains of 32.2 grams per 100 cc. against losses of 20.7 grams per 100 cc. Ten grams approximately have been added during alteration.

The type of alteration differs notably from the normal sericitic

type. In contrast to the propylitic alteration there has been a vigorous exchange of constituents.

In contrast to the sericitic type there has been strong addition of iron silicates besides more or less sericite. All of the soda and most of the lime is gone, also a considerable part of the potassa, while in sericitic alteration an addition of potassium is often noted. In sericitic alteration the development of chlorite is an initial and transitory process.

The alteration is not identical with that producing the typical "greisen," consisting mainly of quartz, mica, and topaz or tourmaline. Yet in the removal of potassium in part and in the addition of iron to form silicates the process is allied to that producing greisen.

The Iron Chlorites.—Chemically, the group of the iron-rich chlorites are in a deplorable confusion. It appears that many of the chlorites in ore deposits are of a distinct species, rich in ferrous iron and poor in magnesia. They have a stronger birefringence than penninite or prochlorite and a notably higher index of refraction. They often show zonal structure indicating isomorphous mixtures. They are prominent in hypothermal, fairly common in mesothermal, not common in epithermal ore deposits. They are probably not prochlorite. Many names like daphnite, aphrosiderite, etc., have been given to members of this species which will bear much additional study. The following determinations of maximum indices are tabulated:

Penninite	1.578	Larsen
Penninite	1.579	Larsen
Prochlorite	1.610	Larsen
Aphrosiderite	1.623	Larsen
Daphnite	1.649	Larsen
Thuringite (Creede)	1.637	Larsen
Thuringite (Creede, Colorado)	1.643	Larsen
Thuringite (Creede, Colorado)	1.605	Larsen
"Chlorite" (Caracoles, Bolivia)	1.638	Larsen
"Chlorite" (Dolcoath, Cornwall)	1.660	Larsen
"Chlorite" (Argentine, Bolivia)	1.644	Lindgren
"Chlorite" (Premier Mine, B. C.)	1.65	W. D. Burton

SUMMARY.

A brief characterization is given of the tin veins at Caracoles, Bolivia. They are narrow replacement veins in granite and of a hypothermal type. The rock briefly called granite is really a quartz monzonite of the Cordilleran Tertiary petrographic region, allied to many rocks in the Cordilleran section of the United States. The ores contain mainly cassiterite, tourmaline, chlorite, quartz, and a small amount of sulphides, indicating a replacement tending to concentrate tin, boron, ferrous iron, and magnesia.

The altered country rock contains but little tourmaline, pyrite, and cassiterite, but much chlorite and sericite. The trend of the alteration is characterized as hypothermal and marked by loss of sodium and calcium, a moderate loss of potassium, and a strong gain of iron and water, besides a moderate gain of magnesium. Carbonates are almost absent, likewise pyrite.

The facts tell the story of genesis so plainly that he who runs may read. There has been no injection of an "ore magma." There has been an injection of highly mobile aqueous solutions containing silica, tin, boron, iron and magnesia, and little sulphur, which gradually changed the granitic rock to ore along narrow fissures, and which permeated the rock beyond for a moderate distance effecting a similar feebler change. The present ore contains abundantly of the compounds of the granitic rock. The hypothermal solutions doubtless emanated from the deeper part of the granite, but were constantly changing in composition, taking up elements of the rock in exchange for iron, tin, and boron. Thus the liquid, originally of purely magmatic origin, rapidly changed to one of mixed origin. When it entered the surrounding slates we may safely assume that it was still further diluted.

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SOME EVIDENCE ON THE VARIATION OF TEMPERATURE WITH GEOLOGIC STRUCTURE IN CALIFORNIA AND WYOMING OIL DISTRICTS.[1]

C. E. VAN ORSTRAND.

INTRODUCTION.

My first attempt to correlate temperatures with structure was made in 1919 in Oklahoma working in coöperation with Dr. George C. Matson, Chief Geologist of the Gypsy Oil Company. Owing to various imperfections, the observations failed to yield any definite conclusions concerning the problem in question. Immediately following these tests work was undertaken in the California and Wyoming oil regions. A detailed program was not followed except that during any particular visit to a field, tests were made in all of the wells that happened at that time to be suitable for temperature measurements. By proceeding in this manner, a random distribution of wells was obtained such as might be expected in the usual process of locating a structure by drilling to the sand. A few scattering observations made in the summer of 1920 showed variations of temperature with structure; in the summer of 1922, 10 tests at Salt Creek, Wyoming, showed a marked dependence of temperature on structure; and in the following summer, 12 additional tests substantiated the results of the preceding year. The observations and reductions are far too extensive to permit of publication in a short paper—a brief summary of the most important results together with a few tabulations indicating the scope of the investigation is all that can be given here.

Method of Observation:—The observations were made with the hand operated machine described in my paper,[2] "Apparatus for the measurement of temperatures in deep wells by means of maximum thermometers." The instrumental error of observa-

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Economic Geology, vol. XIX., No. 3, pp. 229–248, April–May, 1924.

tion at any depth does not exceed 0.2 or 0.3° Fahrenheit. The chief source of error is unstable temperature equilibrium due to recent drilling, cementing of wells, circulation of fluids, and other disturbing influences. For this reason all of the wells were selected with the greatest care and with the particular object in view of eliminating all sources of extraneous heat so that the observed values would represent as nearly as possible true rock temperatures.

DATA OF OBSERVATION AND SOME RESULTING CONSTANTS.

The first four columns of Table I. contain the data of ob-

TABLE I.

TEMPERATURE MEASUREMENTS.

Deep Well, Hardendorff, 1–A.

Location, N.W. ¼ sec. 10, 200 feet south, 200 feet west, T. 39 N., R. 79 W., Salt Creek, Natrona County, Wyoming.

Depth.		Observed Temperatures.		100–1,000 Ft.		100–2,750 Ft.		Constants. 100–1,000 Ft.	Remarks.
Meters.	Feet.	Cent.	Fahr.	Comp. Temp.	Obs. Minus Comp.	Comp. Temp.	Obs. Minus Comp.		
00.0	000	8.2	46.7	50.3	−3.6	47.0	−0.3	a = 50.30 b = 0.01781	Water, 533 feet.
30.5	100	11.4	52.5	52.1	+0.4	49.4	+3.1	$1/b$ = 56.1 r = ±0.41	8″ casing.
76.2	250	12.7	54.8	54.8	0.0	52.9	+1.9	r_a = ±0.35 r_b = ±0.00057	0–390 feet, shale.
152.4	500	14.8	58.6	59.2	−0.6	58.7	−0.1	100–2,000 ft.	390–500 feet, Shannon sand.
228.6	750	17.3	63.2	63.7	−0.5	64.5	−1.3		
304.8	1,000	20.4	68.7	68.1	+0.6	70.4	−1.7	a = 48.45 b = 0.02146	500–2,700 feet, sand, shale.
381.0	1,250	23.1	73.6	72.6	+1.0	76.2	−2.6	$1/b$ = 46.6 r = ±1.05	2,700–2,810 feet, "First Wall Creek sand."
381.0	1,250	23.2	73.7	.....	.....	.....	.....	r_a = ±0.66 r_b = ±0.00055	
457.2	1,500	26.5	79.7	77.0	+2.7	82.1	−2.4	100–2,750 ft.	2,810–3,097 feet, sand, shale.
533.4	1,750	30.4	86.8	81.5	+5.3	87.9	−1.1		
609.6	2,000	34.2	93.5	85.9	+7.6	93.8	−0.3	a = 47.02 b = 0.02337	3,097–3,103 feet, "Second Wall Creek sand."
685.8	2,250	38.1	100.6	90.4	+10.2	99.6	+1.0	$1/b$ = 42.8 r = ±1.33	
762.0	2,500	41.9	107.4	94.8	+12.6	105.4	+2.0	r_a = ±0.73 r_b = ±0.00045	
838.2	2,750	44.9	112.8	99.3	+13.5	111.3	+1.5		

TABLE I.

TEMPERATURE MEASUREMENTS (*Continued*).

Deep Well No. 12, Coalinga-Mohawk Oil Company.
Location (Coalinga) N.W. ¼ sec. 12, T. 20 S., R. 15 E., Fresno County, Calif.

Depth.		Observed Temperatures.		100–1,000 Ft.		100–3,000 Ft.		Constants 100–1,000 Ft.	Constants 100–3,000 Ft.
				Comp. Temp.	Obs. Minus Comp.	Comp. Temp.	Obs. Minus Comp.		
Meters.	Feet.	Cent.	Fahr.						
00.0	000	17.3	63.2	70.7	−7.5	71.2	−8.0	a = 70.74 b = 0.02043	a = 71.20 b = 0.01961
30.5	100	22.7	72.8	72.8	−0.1	73.2	−0.5	$1/b$ = 49.0	$1/b$ = 51.0
								r = ±0.12	r = ±0.24
30.5	100	22.6	72.7	.....	.....	73.2	.....	r_a = ±0.12	r_a = ±0.17
								r_b = ±0.00018	r_b = ±0.00009
152.4	500	27.3	81.1	81.0	+0.1	81.0	+0.1	100–2,000 ft.	100–4,000 ft.
304.8	1,000	32.8	91.1	91.2	−0.1	90.8	+0.3		
								a = 71.11	a = 71.27
457.2	1,500	38.4	101.1	101.4	−0.3	100.6	+0.5	b = 0.01978	b = 0.01957
								$1/b$ = 50.6	$1/b$ = 51.1
								r = ±0.24	r = ±0.02
609.6	2,000	43.5	110.3	111.6	−1.3	110.4	−0.1	r_a = ±0.20	r_a = ±0.01
762.0	2,500	48.9	120.1	121.8	−1.7	120.2	−0.1	r_b = ±0.00016	r_b = ±0.00001
914.4	3,000	54.4	129.9	132.0	−2.1	130.0	−0.1	100–2,500 ft.	100–4,320 ft.
1,066.8	3,500	59.8	139.6	142.2	−2.6	139.8	−0.2	a = 71.16	a = 71.17
								b = 0.01966	b = 0.01964
1,219.2	4,000	65.3	149.6	152.4	−2.8	149.7	−0.1	$1/b$ = 50.9	$1/b$ = 50.9
								r = ±0.24	r = ±0.02
1,316.7	4,320	69.2	156.5	159.0	−2.5	155.9	+0.6	r_a = ±0.18	r_a = ±0.01
								r_b = ±0.00012	r_b = ±0.00001

servation for two wells expressed in both English and metric units. Graphs of the corresponding depth temperature curves are shown by the heavy continuous lines in Figs. 1 and 2. The Coalinga curve approaches closely to linearity, but the Salt Creek curve is both convex and concave with respect to the depth axis. It will be sufficient for our purpose, however, to represent the general trend of the curve by means of the straight line equation

$$y = a + bx, \qquad (1)$$

wherein

y = temperature expressed in the Fahrenheit scale
x = depth in feet

a = computed mean annual temperature
b = gradient expressed in degrees Fahrenheit per foot
$1/b$ = reciprocal gradient expressed in feet per degree Fahrenheit.

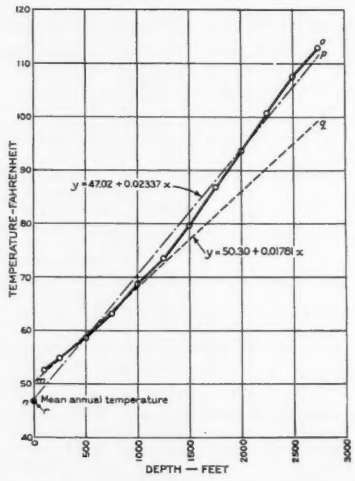

FIG. 1. Depth-temperature curve, deep well, Hardendorf, 1–A. See Table I.

The parameters a and b of the straight line equation (1) were computed by the method of least squares and are tabulated in the column designated "Constants" along with their probable errors, r_a and r_b, and the probable error (r) of an observation of weight unity. The constants of the dotted straight line mq (Fig. 1) were computed from the first five observations, beginning at 100 and ending at 1,000 feet. For depths in excess of 1,000 feet the computed straight line falls considerably below the observed curve. The differences between the observed and computed values are designated "Observation minus computation" and are tabulated in the sixth column of the table. At a depth of

2,750 feet, the difference *oq* as shown by both table and graph amounts to + 13.5° Fahrenheit. The constants of the straight line *np* are based on all of the observations. The computed

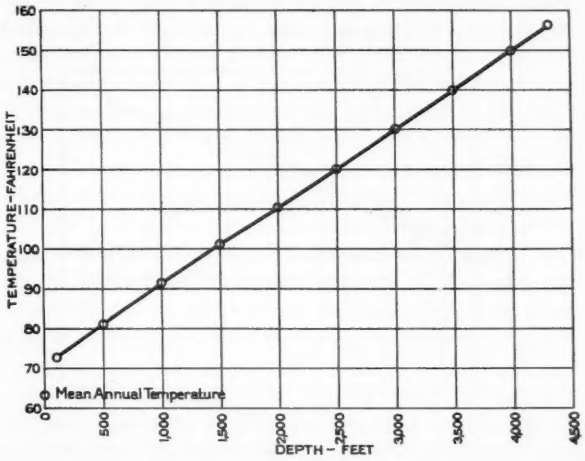

FIG. 2. Depth-temperature curve, deep well, No. 12, Coalinga-Mohawk Oil Company. See Table I.

values are tabulated in the seventh column of Table 2, while in the eighth column are tabulated the differences between the observed and computed values. The difference at 2,750 feet amounts to 1.5° Fahrenheit.

Comparison of the Computed and Observed Mean Annual Temperatures.—The physical significance of the quantities *a* and *b* in equation (1) is shown in Fig. 3. The value

$$y = oe = a \text{ for } x = o$$

represents the computed value of the mean annual temperature at a point just beneath the plane surface of the ground. The corresponding observed value, *fo*, at a point just above the plane surface of the ground is interpolated from the volume on Clima-

tological Data for the United States by Sections, published by the U. S. Weather Bureau.

As shown in Table I. and Fig. 1, the interpolated value for the Hardendorf well is 46.7° Fahrenheit. This value compares favorably with the computed value, $a = 50.30°$ F., contained in

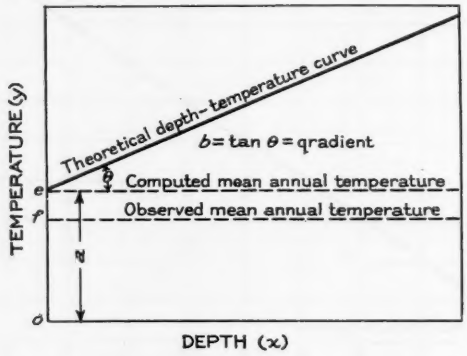

FIG. 3. Sketch showing physical significance of the quantities (a) and (b) in the equation of the straight line (Equation 1).

the column designated "Constants" and retabulated in the column designated "Computed temperatures." The excess of soil temperature over air temperature, the quantity *mr* in Fig. 1 and *fe* in Fig. 3, amounts therefore in this case to 3.6° F., a result which is rather large except for certain areas in California in which the excess may exceed 8 or 10° F. The Coalinga curve, Fig. 2, is typical in this respect. Ordinarily, however, differences between the observed and computed values of the mean annual temperature showing an excess of 3 or 4° F., or more, should be regarded as due either to abnormal temperatures in the surface rocks or to errors in the observed and interpolated values. Errors in the interpolations based on Climatological Data may be quite large on account of the great distance of the Weather Bureau Station from the point of observation; and unless excep-

tional care is used in observing rock temperatures at depths not exceeding 1,000 feet, errors of considerable magnitude in the observed values may be introduced by accidental exposure of the thermometers to the heated atmosphere at the surface of the ground. The latter source of error has been eliminated in these observations, nevertheless, some of the depth temperature curves show anomalies near the surface which must be due either to unstable temperature equilibrium within the well or to the circulation of surface water on the outside of the casing.

Some Characteristics of the Depth-Temperature Curves.—Referring to the column designated " Constants " for the Salt Creek data, Table I., it will be noted that the values of b increase while the values of a and $1/b$ decrease with increasing range of depth The general trend of the curve is evidently concave upward as shown in Fig. 1. As the errors of observation are small in comparison with the deviation of the curve from linearity, the probable error (r) becomes in this case a measure of the departure of the curve from a straight line. Nearly all of the Salt Creek curves contain a point of inflexion about midway between the top and the bottom of the well; the curve first rises slowly, then more rapidly, and again more slowly. The observed curve, Fig. 1, is an extreme case of this type of curve. The Coalinga curve, Fig. 2, is very exceptional in that it approximates very closely to a linear distribution of temperatures.

Evaluation of the Reciprocal Gradient ($1/b$).—The curvature of the depth-temperature curves just discussed introduces a slight irregularity in the evaluation of the values of $1/b$. If the curves were straight lines and the excess of soil temperatures over air temperatures were constant, the computation could be based on the temperature at any depth. As neither of these conditions is strictly fulfilled, it becomes necessary to approximate as nearly as possible to the ideal state.

The observed temperatures near the surface of the ground represent the resultant effects of topography, surface waters, nature of the soil and so on. It may be assumed that these anomalies are very small or disappear altogether at depths in excess of

about 1,000 feet. The values of the excess of soil temperature over air temperature, as determined by observation and computation vary considerably even in the same field, and it is necessary in order to have a standard of reference in a field, to assume a constant value for this quantity. Following the practice of the Committee on Underground Temperatures of the British Association for the Advancement of Science (Report 1882), I have used the value of 1° F., which is fairly representative for all except the anomalous values found in the California fields. The precise value is not of importance except for the determination of the absolute value of $1/b$. The relative values which are needed in the construction of the maps are not seriously affected by this error. The chief source of inconsistency is the deviation of the curve from a straight line. If a sufficient number of observations were available, it would probably be found that the curvature varies with the dip of the rocks or some other geologic feature. For present purposes, there appears to be at least four different methods of dealing with this anomaly: (1) we may plot the isogeothermal surfaces; (2) we may evaluate $1/b$ at a given point from the general trend of the depth-temperature curve at that point (reciprocal of first derivative); (3) we may compute the value of 1/b from the temperature at a given depth and the mean annual temperature to which we add 1° F. to correct for the emissivity at the surface of the earth; and (4) we may proceed as in (3) with the exception that the temperature at the greatest depth in each well is used instead of the temperature at a constant depth. The application of the first method to the Salt Creek data will be considered in the next paragraph. Anomalies in the depth-temperature curves preclude the use of the second method for depths which are less than 1,000 or possibly 1,500 feet. In Table II. are summarized the results obtained by application of the last two methods to the data obtained from seven oil fields. It was necessary in a few instances to approximate to the constant depth adopted in a particular field.

Variation of the Reciprocal Gradient ($1/b$).—The summaries contained in Tables I. and II. show that the values of $1/b$ in a

TABLE II.

SUMMARY OF RECIPROCAL GRADIENTS ($1/b$).

Rawlins. (Observations, July, 1920.)

	Location.			
	NW. ¼ sec. 5. 700′ from north line. 300′ from west line.	NW. ¼ NE. ¼ sec. 17. 480′ east, 160′ south of north quarter cor. of sec.	SW. cor. NE. ¼. NW. ¼ sec. 31.	SW. ¼ SE. ¼, sec. 31. 930′ east, 1,000′ north south quarter corner of sec.
	T. 25 N., R. 86 W.	T. 25 N., R. 86 W.	T. 26 N., R. 86 W.	T. 26 N., R. 86 W.
Depth..	1,500	1,500	1,500	1,500
$1/b$....	63.0	57.7	47.3	53.2
Depth..	3,000	2,000	.....	2,900
$1/b$....	56.3	56.8	.....	51.8

Thermopolis. (Observations, July, 1920.)

	Location.			
	Center NE. ¼, NW. ¼ sec. 35.	SW. cor. SE. ¼, NE. ¼ NW. ¼, sec. 35.	SW. cor. NE. ¼, SE. ¼ NW. ¼.	NW. cor. NE. ¼, NE. ¼ sec. 36.
	T. 43 N., R. 94 W.	T. 43 N., R. 94 W.	T. 43 N., R. 94 W.	T. 43 N., R. 94 W.
Depth..	895	900	900	945
$1/b$....	20.2	20.8	21.4	21.3

Salt Creek. (Observations, 1922–23.)

	Location.			
	NE. ¼ sec. 3.	SE. ¼ sec. 1. 1,101′ south, 648′ west.	SW. ¼ sec. 11. 229′ west, 697′ south.	NW. ¼ sec. 29.
	T. 39 N., R. 79 W.	T. 39 N., R. 79 W.	T. 40 N., R. 79 W.	T. 40 N., R. 78 W.
Depth..	1,435	1,500	1,500	1,500
$1/b$....	31.5	28.7	44.8	37.1
Depth..	.....	.....	.....	2,500
$1/b$....	.....	.....	.....	36.9

	Location.			
	NE. ¼ sec. 22, 660′ north, 205′ west.	NW. ¼ sec. 12.	NW. ¼ sec. 3, 1,095′ north, 505′ east.	E. ½ sec. 12.
	T. 40 N., R. 79 W.	T. 40 N., R. 79 W.	T. 39 N., R. 79 W.	T. 39 N., R. 79 W.
Depth..	1,500	1,500	1,500	1,500
$1/b$....	39.2	35.5*	41.8	32.5
Depth..	2,080	2,160	.....	2,000
$1/b$....	40.4	40.3	.....	33.6

* Excess of soil temperature over air temperature = 16.6° F.

Salt Creek (Cont.).

	Location.			
	NW. ¼ sec. 34. T. 40 N., R. 79 W.	SW. ¼ sec. 7. T. 39 N., R. 78 W.	SE. ¼ sec. 12. T. 40 N., R. 79 W.	NW. ¼ sec. 12. T. 40 N., R. 79 W.
Depth..	1,500	1,500	1,500	1,500
I/b....	36.3	31.3	38.1	38.9
Depth..	1,850	2,200	2,240	2,000
I/b....	36.0	33.0	40.4	40.5

	Location.			
	SE. ¼ sec. 6. T. 39 N., R. 78 W.	NW. ¼ sec. 3. 215′ north, 681′ east. T. 39 N., R. 79 W.	NW. ¼ sec. 10. 200′ south, 200′ west. T. 39 N., R. 79 W.	E. ½ SW. ¼ sec. 20. 205′ north, 205′ east. T. 39 N., R. 78 W.
Depth..	1,430	1,500	1,500	1,500
I/b....	30.2	41.2	46.9	36.5
Depth..	.....	2,000	2,750	2,600
I/b....	.....	39.5	42.2	36.5

Salt Creek (Cont.).

	Location.			
	NE. ¼ sec. 14. T. 40 N., R. 79 W.	SW. cor. SE. ¼, SE. ¼ sec. 17. T. 39 N., R. 78 W.	NW. ¼ sec. 15. 291′ south, 308′ east. T. 40 N., R. 79 W.	SE. ¼ sec. 11. T. 40 N., R. 79 W.
Depth..	1,500	1,500	1,500	1,500
I/b....	36.2*	35.5	49.7	39.5
Depth..	1,750	2,380	2,650	2,000
I/b....	39.2	34.5	47.6	40.2

	Location.			
	W. ½ NE. ¼ sec. 18. 200′ south, 200′ west. T. 39 N., R. 78 W.	NW. cor. sec. 16. 590′ south, 65′ east. T. 39 N., R. 78 W.	Sec. 28.† T. 39 N., R. 78 W.	
Depth..	1,500	1,100	1,500	
I/b....	31.2	38.9	39.4	
Depth..	2,200	.....	2,736	
I/b....	33.2	.....	36.7	

* Temperature too high, probably on account of hot mud on outside of casing.
† Teapot dome.

Lost Soldier. (Observations, 1923.)

Location.	NW. ¼ sec. 10. 2,330′ south, 2,440′ east. T. 26 N., R. 90 W.	NW. ¼ sec. 11. 125′ south, 353′ east. T. 26 N., R. 90 W.	SW. cor. SW. ¼ sec. 2. T. 26 N., R. 90 W.
Depth..	1,500	1,500	1,500
1/*b*....	30.4	19.6	20.3
Depth..	3,400	1,845	1,925
1/*b*....	37.9	19.3	19.2

Grass Creek. (Observations, 1920.)

Location.	NE. ¼ SW. ¼ sec. 20. T. 46 N., R. 98 W.	SW. ¼ SW. ¼ sec. 20. T. 46 N., R. 98 W.	NE. ¼ SW. ¼ sec. 18. T. 46 N., R. 98 W.
Depth..	750	750	750
1/*b*....	46.0	49.7	46.7

Lance Creek. (Observations, Nov., 1919.)

Location.	N. ½ sec. 2. T. 35 N., R. 65 W.	S. ½ sec. 30. T. 36 N., R. 64 W.	NW. ¼ sec. 1. T. 35 N., R. 65 W.
Depth..	2,000	2,000	2,000
1/*b*....	33.8	32.6	34.0
Depth..	3,000	3,000	3,000
1/*b*....	34.8	34.7	35.8

TABLE III.

SUMMARY OF RECIPROCAL GRADIENTS (1/*b*).

Coalinga. (Observations, 1920.)

Location.	NW. ¼ sec. 12. T. 20 S., R. 15 E.	NE. ¼ sec. 12. T. 20 S., R. 15 E.	NW. ¼ sec. 12. T. 20 S., R. 15 E.	NW. ¼ sec. 11. T. 19 S., R. 15 E.	S. ½ sec. 2. T. 19 S., R. 15 E.
Depth..	2,000	2,000	2,000	2,000	2,000
1/*b*....	43.4	44.4	44.3	53.9	54.9
Depth..	4,320	3,500	3,928	.....	.....
1/*b*....	46.8	46.4	49.0	.....	.....

particular field are not constant. Furthermore, in four of the fields, Warm Springs, Lost Soldier, Salt Creek, and Lance Creek, the values are abnormally small. This interesting result, when discovered at Warm Springs, was naturally associated with the

high temperatures found in the hot springs and two flowing wells at Thermopolis [3] about six miles west of Warm Springs domes. Subsequent observations, however, revealed even more rapid rates of temperature increase at Lost Soldier far removed from any areas in which there is any evidence of thermal activity. The fact that these values are highly abnormal suggest a variation of temperature with structure for there is no reason for believing that such extreme temperatures are distributed over large areas. Structure maps are available for each of the seven fields—Coalinga, California; and Warm Springs, Lost Soldier, Ferris Dome, Grass Creek, Lance Creek, and Salt Creek, Wyoming, Figs. 4–11. On these maps the locations of the wells are indi-

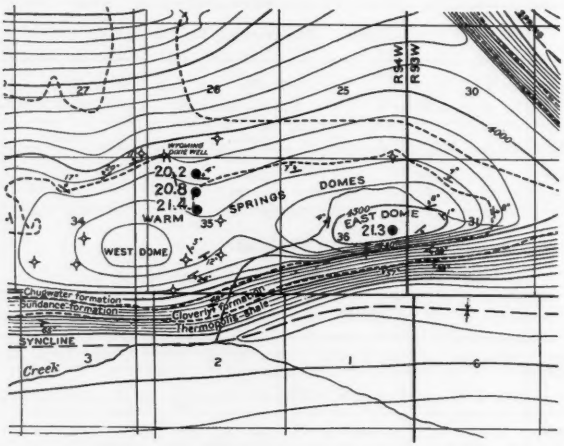

FIG. 4. Warm Springs domes. Structure map by A. J. Collier, from "Oil in the Warm Springs and Hamilton Domes," near Thermopolis, Wyoming. U. S. Geol. Survey, Bull. 711, p. 68, 1920.

cated by small solid circles and the values of $1/b$, the number of feet per degree Fahrenheit of temperature increase, is written

[3] Van Orstrand, C. E., "Temperatures in Some Springs and Geysers in Yellowstone National Park, *The Journal of Geology*, vol. 32, No. 3, pp. 211–212, April–May, 1924.

near the circle. The results shown on the maps suggest the conclusion that the highest temperatures are found at or near the top of the structure; the temperatures at a given depth diminish with rather marked regularity as the horizontal distance from the crest of the structure increases. An exception may perhaps be noted in the Grass Creek data, but the wells in this field are very shallow and the results are no doubt vitiated to a certain extent by pumping operations; consequently the slight irregularities found in this field are of no particular consequence.

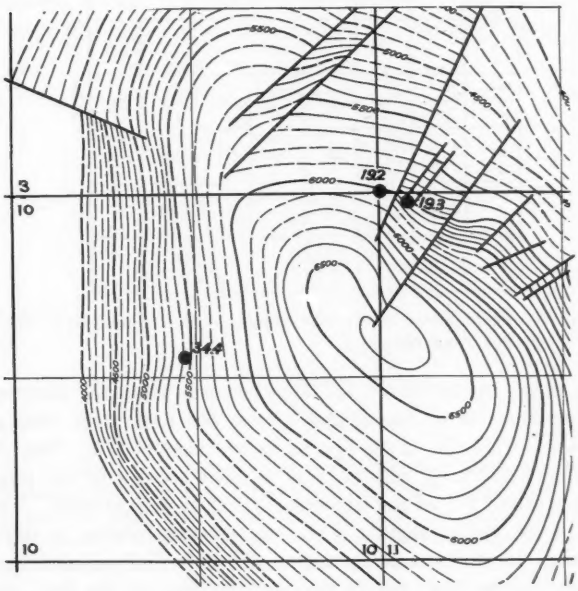

FIG. 5. Lost Soldier Dome. Structure map by A. E. Fath and G. F. Moulton, from "Oil and Gas Fields of the Lost Soldier-Ferris District, Wyoming," U. S. Geological Survey Bull. 756, p. 32, 1924.

A sufficient number of observations have been made in the Salt Creek field to permit of drawing some of the lines which

represent equal values of $1/b$. All of the observations, 22 in number were used by Dr. W. T. Thom, Jr., in the construction of the heavy continuous contours shown in Fig. 1 of his paper.[4] The values of $1/b$ are based on the temperatures observed at maximum depths, and are tabulated in Table 2. In Fig. 9 of

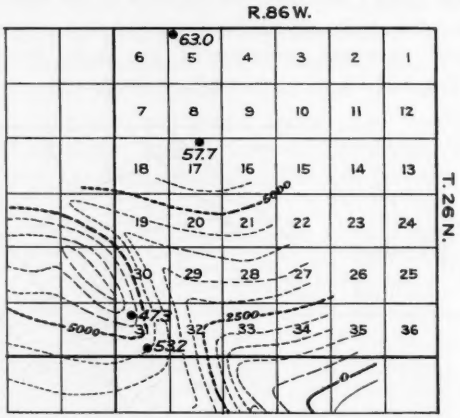

FIG. 6. Ferris Dome. Structure map by A. E. Fath and G. F. Moulton. See page 4, *op. cit.*

this paper, the values of $1/b$ are computed from the observed temperatures at or immediately above the 1,500 foot level as shown in Table II., in the first series of values of $1/b$. One observation, N.W. ¼ sec. 12, was rejected because of the large excess (16.6° F.) of soil temperature over air temperature. The two maps differ slightly. The second map shows a slight anomaly in the extreme northern end of the field which is not shown on the first; but in the southern half of the field, the contours on the second map agree somewhat more closely with the structure contours on the "Second Wall Creek sand" than do those on the first map.

[4] Thom, Jr., W. T., "Relation of Earth Temperatures to Buried Hills and Anticlinal Folds," ECON. GEOL., vol. 20, No. 6, pp. 524–530, September–October, 1925.

In Fig. 10, the isogeothermal lines corresponding to a temperature of 80° F. have been drawn. The numbers in this case thus represent the depth at which a temperature of 80° F. is reached. The three maps are obviously in close agreement, and in each case, a marked dependence of temperature on structure is revealed.

SOME GENERAL SUGGESTIONS AND CONCLUSIONS.

The computed values of the constants, *a* and *b*, constitute a permanent record, useful for various purposes. The values of the computed mean annual temperature, *a*. determined from the

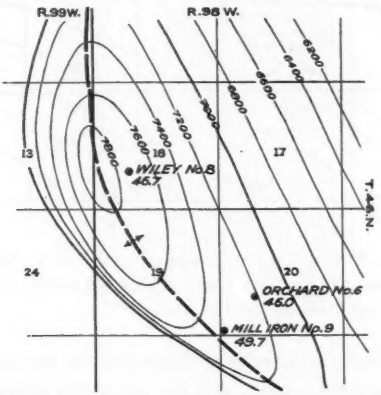

FIG. 7. Grass Creek Dome. Structure map by E. L. Estabrook, from "Production Problems in the Grass Creek Oil Field." *Trans. Am. Inst. Min. and Met. Eng.*, vol. 68, pp. 1130–1137, 1923. See also, Hewett, D. F., and Lupton, C. T., "Anticlines in the Southern Part of the Big Horn Basin, Wyoming," U. S. Geol. Surv. Bull. 656, p. 160, 1917.

first range of depths, 100 to 1,000 feet, are needed for comparison with future interpolations of the observed mean annual temperature; and the difference between the observed and computed mean annual temperatures constitutes a criterion of accuracy for the general trend of the upper part of the depth-temperature curve.

Speculations in explanation of the cause of variation in temperature gradients have been current in the literature[5] for a number of years. Apart from magmatic and dynamic influences, the variations are generally attributed to chemical evolu-

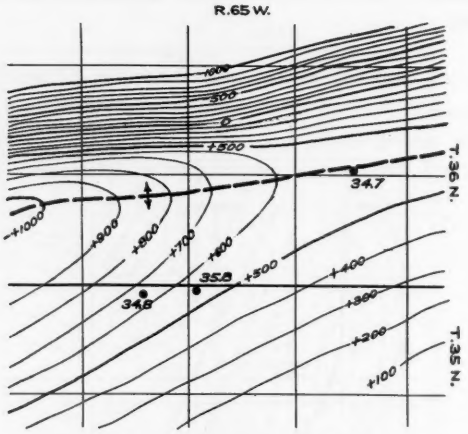

FIG. 8. Lance Creek Dome. Structure map by E. T. Hancock, from "The Lance Creek Oil and Gas Field, Niobrara County, Wyoming," U. S. Geol. Surv. Bull. 716, pp. 91–122, 1921.

tion, and thermal conductivity as dependent on the nature of the rocks, their moisture content, and the dip of the strata. For the

[5] Koenigsberger, J., and Mühlberg, M., "On Measurements of the Increase of Temperature in Bore Holes; with the Depth, the Technics, and Practical Importance of the Same for Geological Prognosis, with Reference to New Measurements in Mexico, Borneo, and Central Europe," *Trans. The Institute of Mining Engineers*, vol. 39, part 4, pp. 1–28, June, 1910.

Krige, L. J., and Pirow, H., "Temperature Measurements in the Dubbledevlei Bore Hole, Carnarvon District," *Trans. Geol. Soc. South Africa*, vol. 26, pp. 50–64, June, 1923.

Jones, T. David, "Geological Disturbances and their Effect on Strata Temperature," *Proc. The South Wales Institute of Engineers*, vol. 41, No. 2, pp. 141–155, April 23, 1925; "Further Investigations of Strata Temperatures in the South Wales Coal Field," *Proc. The South Wales Institute of Engineers*, vol. 41, No. 2, pp. 157–169, April 23, 1925.

most part, it is impossible at present to either prove or disprove these hypotheses. Additional observations in both field and laboratory must be made before a decision of real value can be reached. It is reasonable to suppose that oil diffuses heat more slowly than water, and for that reason, it may be expected that

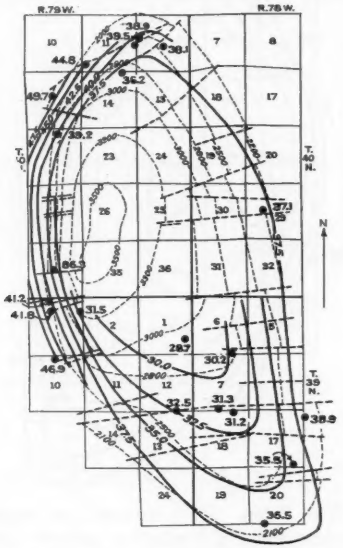

FIG. 9. Salt Creek Dome. The continuous lines represent equal values of $1/b$, expressed in feet per degree Fahrenheit. The well locations and the contours (broken lines) on the "Second Wall Creek sand" are from an unpublished map by Mr. C. H. Wegemann.

the temperatures at a given depth diminish as we pass from the oil to the water bearing portion of the strata. Inclined strata on the flanks of the fold probably produce similar effects, and the two effects combined may perhaps be sufficient to produce the observed variations; on the other hand, it is rather difficult to see how differences in conductivity alone will suffice to explain the

extremely high temperatures found at Warm Springs, Lost Soldier, Lance Creek and Salt Creek. The upward movement of rocks at great depths resulting from isostatic adjustment as ero-

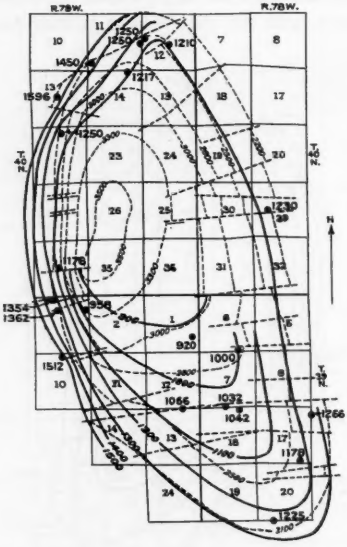

FIG. 10. Salt Creek Dome. The continuous lines represent the depths at which a temperature of 80° Fahrenheit is reached. The broken lines are the same as in Fig. 9.

sion proceeds, suffices to explain both of the important facts—the high temperatures and the distribution of temperatures—but no geodetic evidence has yet been obtained to show that such small areas of the kind here considered are in a state of isostatic equilibrium.

From the preceding brief discussion, it is evident that the problem of variation of temperature with structure involves a great number of unknown factors in which even the sequence of events may play an important part. It is therefore impossible at this

time to establish a fixed relation between temperature on the one hand and structure on the other, such that when one is given the other can be predicted. The observations at Coalinga, Warm Springs, Lost Soldier, Ferris Dome, Lance Creek, and Salt Creek suggest the possibility of locating the highest point on some of the structures with a considerable degree of precision; and the

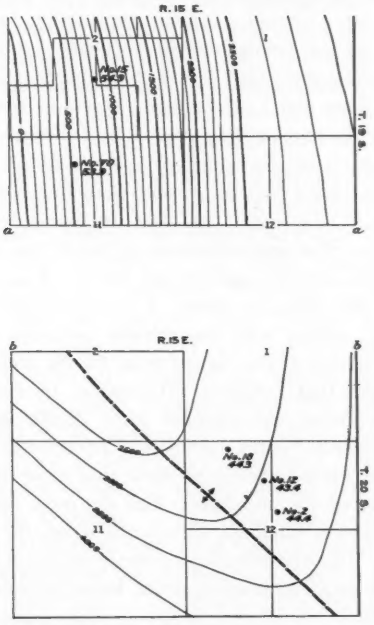

FIG. 11. Coalinga anticline. Distance $ab = 5$ miles. Structure map by Ralph Arnold and Robert Anderson, from "Geology and Oil Resources of the Coalinga District, California," U. S. Geol. Surv. Bull. 398, 1910.

observations at Salt Creek, Ferris Dome, Lost Soldier, and Coalinga show that the isogeothermal surfaces stand in a definite relation to the surface of the oil sand which approaches parallel-

ism; but in general, it is to be expected that the increase in the water content of the rocks will cause the distance between these surfaces to diminish as edge water and the axis of the syncline are approached. This conclusion is in agreement with the recent observations of T. David Jones [6] who finds that the values of the reciprocal gradients in the coal fields of South Wales vary from about 1° F. in 60 feet on the anticlines to 1° F. in 75 feet in the synclines. I have offered a similar explanation to account for the variation of the gradient in the vertical.[7]

The extremely small values of $1/b$, 1° F. in 19 or 20 feet, found at Warm Springs and Lost Soldier suggest at once that these wells are near the tops of the domes. In two other fields, Lance Creek and Salt Creek, the values of $1/b$ are sufficiently small to lead to the conclusion that these wells were favorably located on the structure. Data from four wells on Ferris Dome, Fig. 6, suffice to give a close approximation to one of the cross-sections of the structure; and in addition, the value $1/b = 47.3$ in comparison with the adjacent values, $1/b = 53.2$ and $1/b = 57.7$, enables one to predict with considerable certainty the direction from these locations of the highest point on the dome. It is important to note that sufficient information to locate approximately Ferris Dome was obtained from depths of 1,500 feet (Table II.) while at Warm Springs and Lost Soldier, a depth of 1,000 feet was quite sufficient to show that these locations were near the crests of the anticlines. But the most remarkable result was obtained at Coalinga, California, where the observations at 2,000 feet, Fig. 11, indicated correctly proximity to the axis of an anticline on an oil bearing strata, buried to a depth of more than 4,000 feet.

It will be noted that the variation of temperature with structure at Coalinga, although pronounced and unmistakable, is never the less, much smaller than in the Wyoming fields. This result naturally suggests the question as to the generality of our

[6] See p. 168, reference 5.

[7] Temperature measurements. West Virginia Geological Survey, County Reports, p. 58, 1918 (Barbour, Upshur, and Western Portion of Randolph County).

evidence—is there any reason for believing that all structures show a marked temperature variation. The correct answer to this question can be found only by making careful tests just before drilling into the pay sand in a large number of fields. In the meantime, it may not be unreasonable to surmise that large variations will be found on sharp structures carrying large quantities of oil while over flat structures carrying small quantities of oil the variation may be so small as to evade detection even by means of the most refined observations. Between these two extremes, we may perhaps expect varying degrees of success.

ACKNOWLEDGMENTS.

Officials and employees of several oil companies assisted in carrying out the extended series of observations on which this paper is based. Among the contributors are Messrs. C. H. Wegemann, Chief Geologist, A. W. Peake, General Superintendent, E. L. Estabrook, Petroleum Production Engineer, and C. M. Rader, Petroleum Engineer, The Midwest Refining Company; Messrs. C. J. Hares, Chief Geologist, and John McFadyen, Manager, The Ohio Oil Company; and Messrs. Max Ball, President, and G. L. Ferguson, Superintendent, The Marine Oil Compony. Messrs. C. E. Beecher and H. B. Hill, then Superintendents, respectively, at Casper and Salt Creek, Wyoming, U. S. Bureau of Mines, assisted in various ways. Mr. F. M. Brewster, Petroleum Engineer, U. S. Bureau of Mines, assisted in making some of the observations at Lost Soldier. Credit is due Mr. C. H. Wegemann for permission to use his elaborate map of the Salt Creek field. To all who have thus contributed so generously, I extend my cordial thanks.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

MOLECULAR MIGRATION AND MINERAL TRANSFORMATION.*

ALFRED WANDKE.

THE experiments to be described below were made in connection with research work carried on at Harvard University in 1923. In the course of this work numerous questions had frequently arisen regarding the cause and nature of some of the intergrowth patterns between various minerals, especially bornite and chalcocite. The similarity between the intergrowth patterns of naturally occurring minerals and the cooling patterns characteristic of steels has often been noted and the resemblance of some of the etch patterns of steel to those of bornite-chalcocite has been commented upon. Microscopic studies also indicated that minerals are not always deposited pure but certain grains may carry sufficient impurities to permit a selective alteration and replacement by later solutions. That the mineral bornite is not deposited pure was also suggested by the rapidity with which certain polished surfaces tarnish as compared with other specimens of bornite and by the way bornite alters under conditions of supergene enrichment. While studying the bornite chalcocite intergrowth patterns it seemed worth while to try some heating experiments upon a few polished specimens of ore minerals. The following results were obtained from this work.

Experiment 1.—A fragment of Butte ore was selected, showing chalcocite and bornite in the typical lattice[1] intergrowth. This intergrowth has variously been explained as due to secondary (supergene) enrichment of bornite by chalcocite; primary

* Presented before the Society of Economic Geologists, New York Meeting, May, 1925.

[1] Resembles widmannstätten figures common to meteorites and found when low-carbon austenite transforms into Alpha iron and pearlite. The structure in steel is due to ferrite precipitated along the crystallographic planes of Gamma iron.

(hypogene) replacement of bornite along crystallographic planes by hypogene chalcocite; an unmixing of primary bornite-chalcocite, the bornite cleavage or crystallographic directions controlling the resulting pattern.

The specimen was polished in the usual way, the minerals identified, and the intergrowth pattern studied. The specimen was next placed polished face down upon a piece of asbestos board and heated over a bunsen flame at a temperature of 200° C. for nine hours. At the end of this time the specimen was removed, quickly cooled by quenching, and then studied under the microscope. The polished surface no longer showed the lattice structure of bornite and chalcocite but presented a blue gray homogeneous field. Touching up the surface lightly on the broadcloth polishing wheel failed to change the appearance of the surface. The specimen was next etched with both nitric acid and potassium cyanide solution but these etching reagents failed to develop the lattice intergrowth pattern which before heating was visible without etching. The heating apparently produced a mixing of the chalcocite and bornite.

Experiment 2.—To check the results of the first experiment another piece of Butte ore showing the typical lattice of bornite-chalcocite was taken, polished, and heated this time in a covered crucible in an electric oven for 15 hours at a temperature of 150° C. This piece of ore in addition to the lattice pattern showed crystals of pyrite resting in the midst of homogeneous chalcocite. Chalcocite was more abundant than in the first specimen. No chalcopyrite was visible in the polished surface. After the period of heating the specimen was quenched as before. The grains of pyrite protruded above the polished surface and the specimen seemed much more friable than before the heat treatment. The polished surface was lightly touched up on the broadcloth polishing wheel and the specimen then studied under the microscope. As before the lattice intergrowth pattern between bornite and chalcocite had vanished. A striking change had, however, taken place in the pyrite. The grains of this mineral resting in chalcocite had been partly altered to chalcopyrite. Between the pyrite

and the chalcocite there was in addition a narrow pinkish colored zone that suggested impure bornite. The altered grains of pyrite, moreover, projected considerably above the polished surface as though, due to an increase in volume in the vicinity of the pyrite, the grain of pyrite had been forced upward by the expansion of the material beneath. The surface of the specimen was next ground down and repolished to see if the chalcopyrite had done more than to plate the pyrite. On the new polished surface chalcopyrite could be seen veining the pyrite in relations similar to those frequently seen in specimens of ore. It was therefore concluded that the effects of heating were not superficial but penetrated the entire specimen.

Experiment 3.—Since chalcocite apparently diffused into pyrite and combined with it to produce chalcopyrite, and since pyrite diffused into chalcocite to produce bornite, a piece of Engels, California, ore was heated to see if by any chance bornite and magnetite which occur intergrown could be made to interact. The polished specimen of Engels ore was accordingly heated in a covered crucible in an electric furnace for 16 hours at a temperature of 160° C. After heating, the specimen was quenched, lightly polished to remove the tarnish and studied. The bornite before heating had been free of chalcopyrite, but after heating it was studded with minute crystals of chalcopyrite having a dendritic or fern-like habit. Neither the magnetite nor the bornite was altered in the least along their contacts. The development of chalcopyrite is explained as due to the segregation of some mineral, perhaps chalcopyrite or pyrite, which either was held in solution in the bornite or as particles of colloidal size had intergrown with bornite. The heating temperature may have increased the molecular activity to the point where segregation was induced.

Experiment 4.—To study further the development of chalcopyrite in bornite specimens of bornite from Engels, California, Texada Island, Canada, Magma, Arizona, Messina, South Africa and Promontorio, Mexico, were polished and heated. The

Promontorio specimen was an intimate intergrowth of bornite and chalcopyrite showing the typical mutual boundary relationships. Analyses had shown the Magma bornite to be impure and the Messina bornite was judged to be pure having been analized by H. C. Merwin of the Geophysical Laboratory. The specimens were heated in the electric furnace at a temperature of 160° C. for 16 hours then removed, quenched and lightly polished as in the previous experiments.

The Magma, Engels and Promontorio bornite specimens were seen in the polished surfaces to be loaded with minute dendritic or tufty crystals of chalcopyrite. The Texada Island and Messina bornite remained unaffected as far as my observations went. Later re-heating of the Texada Island and Messina bornite to a temperature of about 200° C. for 9 hours failed to develop more than exceedingly minute grains of chalcopyrite. It is rather interesting that tiny gash veinlets of native silver in the Texada Island specimen remained unchanged during the heat treatment. As a result of this experiment it was concluded that this heat treatment may cause the segregation of chalcopyrite molecules which are disseminated in the impure bornite. The chalcopyrite, since it does not form in bornite known to be pure, hardly seems to be due to a chemical breakdown of bornite as a result of heating.

Experiment 5.—Since pyrite and chalcocite interact, a piece of Magma, Arizona, ore with only bornite and pyrite was polished and heated to 150° C. for 9 hours to see if bornite and pyrite would interact. On cooling no change was visible in the pyrite although the chalcopyrite formed in the bornite as in the previous experiment. The same specimen was repolished and again heated on a piece of asbestos board over a bunsen flame to a temperature of about 250° C. for 3 hours. On quenching and polishing the specimen the pyrite was seen to be rather completely transformed to chalcopyrite. Thus bornite diffuses into and transforms pyrite to chalcopyrite in the same way as does chalcocite, only the temperature has to be considerably higher in the case of bornite to produce the result.

Experiment 6.—Intergrowths of ilmenite and magnetite are of common occurrence. The magnetite, however, in most of these intergrowths is off-color, having a bluish tone rather than the coffee-brown common to pure magnetite. The bluish color is generally due to the masking of the magnetite color by the intergrown ilmenite. A polished specimen showing typically intergrown ilmenite and magnetite with the ilmenite in part so fine grained as to be hardly visible was heated in a covered porcelain crucible over a bunsen flame to a temperature of about 400° C. for 2 hours. On cooling and re-touching the surface, the magnetite was seen to have lost its bluish color, and the minute ilmenite plates were no longer visible in the magnetite. Instead, magnetite and ilmenite appeared as interlocking crystals and the relations suggested that a segregation of magnetite and ilmenite had taken place. Heating the specimen to about 600° C. for three hours produced no further change in the magnetite or in the ilmenite.

Conclusions.—These heating experiments seem to indicate that the molecules and perhaps also the atoms which go to make up a mineral quite readily undergo movement under the influence of heat. Three different kinds of diffusion effects were produced by this heating: (1) mixing, as illustrated by the obliteration of the bornite-chalcocite lattice; (2) segregation, as shown by chalcopyrite forming in bornite and by the separation of magnetite and ilmenite; (3) mineral transformation, as illustrated by the change to chalcopyrite of pyrite resting in either bornite or chalcocite.

These experiments furthermore indicate that minerals may be deposited in an impure state, the foreign material being disseminated in particles perhaps of colloidal size. It is also possible that changes in the relative amounts of impurities may take place as a given crystal forms. The more impure a given mineral or part of a mineral the more readily it may alter. Bornite and pyrite grains, which have been observed under the microscope with the central part largely altered, may owe this variable ease of re-

placement to some difference in composition due to included impurities. A heat treatment of mineral specimens might readily lead to the identification of cored grains in specimens in which the individual grains show no perceptible alteration. The foregoing experiments are only a beginning and an extended research along the same lines probably would yield some rather interesting information about the alteration of minerals.

GUANAJUATO, MEXICO.

CALIFORNIA GOLD PRODUCTION 1849–1923.[1]

JAMES M. HILL.[2]

INFORMATION concerning early gold-mining in California is largely in the form of story and history. There are practically no sources of real statistical value concerning the gold-mining industry of the State prior to 1891. Beginning with 1897 it has been found possible to make a more elaborate study of the sources of gold production of California from published records.

In 1896 Mr. Charles G. Yale, then Statistician for the California State Mineralogist, prepared a table showing the gold yield of the State by years. In this compilation he had the benefit of personal assistance of such men as J. Ross Browne, R. W. Raymond, J. J. Valentine, and L. A. Garnett, all of whom had real knowledge of the gold production of the State. Mr. Valentine, President of Wells Fargo & Company for years, compiled what was accepted as the best statistics of gold and silver production of the Western States. Mr. Garnett, as manager of the San Francisco refinery, also had most intimate knowledge of the *California gold* producers.

In 1902 Mr. Yale took charge of the San Francisco office of the Division of Mineral Resources of the U. S. Geological Survey and continued his statistical studies of the gold problem. The compilation made by him has been accepted as the best available data on the production of gold in California to 1907.

The brief statement of results so far obtained is a summary of an attempt to segregate the gold yield of California, first by sources, *i.e.*, deep and placer deposits, which was accomplished for the whole period 1849–1923; and second, a further segregation of the deep gold by classes of ore, *i.e.*, dry, copper, lead, and zinc, and the placer yield by methods of working—dredge, drift,

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Presented to Society of Economic Geologists, May, 1925.

hydraulic, and sluice. As will be seen from the following table of California gold yield by decades, it was not possible to carry back the detailed separation for more than 23 years.

The following table by decades is condensed from a yearly table that will be published in the 1924 chapter on California in the Mineral Resources volume of the U. S. Geological Survey. The accompanying curve will give some idea of the relations of the various data, which are presented herewith.

The total production of gold in California since the beginning of mining to 1923, inclusive, is $1,763,027,000, of which the deep mines have produced 31.36 per cent. and the placer deposits 68.64 per cent. During the first 13 years of gold-mining in California, "The Golden Days," a total of $639,106,000 was recovered. In the year 1852 a total of $81,294,700 was recovered, the peak of annual yield in the State. During the 11 years, 1850–1860, the production did not fall below $41,273,000 a year and averaged $49,162,000 a year. This production was practically 99 per cent. from surface placer deposits worked single-handed with limited equipment by sluice methods. Compare this with the last 13 years of California gold yield. In the years 1911–1923, inclusive, the gold production of the State was $235,743,000, a little more than a third as much gold as was produced in the first 13 years of gold-mining in California. Yet, note the differences. The deep mines in this 13-year period produced 55 per cent. and the placers 45 per cent. of the yield, and of the placers the dredges furnished 91 per cent. of the total. Had it not been for the dredge the gold yield of California would have been much lower than the figures given.

During this period, 1848–1923, it may be interesting to trace in brief the changes in mining methods. At first, all the production was from the labor of individual miners working for themselves on the surface gravels. In 1850 some of the ledges at Grass Valley and on the southern end of the Mother Lode, in what is now Tuolumne County, had been discovered, but little time was available in those days to work quartz, when so much rich, easily worked gravel was available for individual work.

GOLD PRODUCTION OF CALIFORNIA, 1848–1923, BY DECADES, IN THOUSANDS OF DOLLARS.

Decade	Deep					Placer					Total
	Dry	Copper	Lead	Zinc	Total	Dredge	Drift	Hydraulic	Sluice	Total	
					1%					*99%*	
1848–1860					6,391					632,715	639,106
					10%					*90%*	
1861–1870					23,488					211,388	234,876
					30%					*70%*	
1871–1880					120,910					51,819	172,729
					75%					*25%*	
1881–1890					37,881					113,644	151,525
					78.23%					*21.77%*	
1891–1900					115,110					32,030	147,140
	62.60%	*2.35%*	*0.11%*	—	*65.06%*	*21.94%*	*3.99%*	*5.29%*	*3.72%*	*34.94%*	
1901–1910	113,875	4,270	191	2	118,338	39,912	7,267	9,618	6,773	63,570	181,908
	53.48%	*1.81%*	*0.20%*	*0.01%*	*55.50%*	*40.60%*	*1.32%*	*1.85%*	*0.73%*	*44.50%*	
1911–1923	126,053	4,275	482	16	130,826	95,720	3,104	4,372	1,721	104,917	235,743
State total, 1849–1923, inclusive					552,944					1,210,083	1,763,027

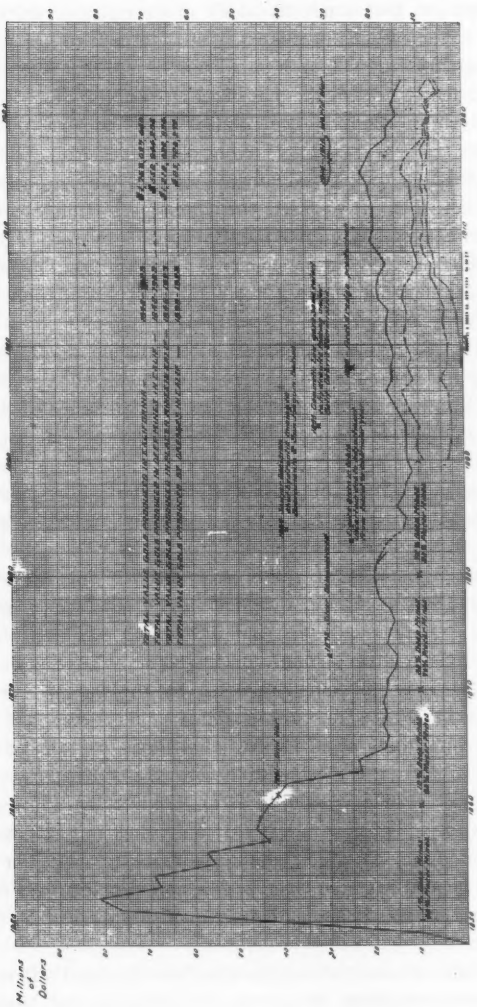

FIG. 1. Curve of Gold Production in California, 1848–1923.

About 1856 the first crude hydraulic placering was started at Nevada City and by 1865 this method of attack of the 500 to 800-foot gravel banks had been perfected so that the period 1866–1876 may be called the "Hydraulic Period" of California gold-mining. In 1876 the agricultural interests began a series of law-suits to recover damages from debris, resulting from hydraulic operations, which culminated in the famous "Sawyer Decision" in 1884 that closed the book on hydraulic mining. To be sure, after many efforts the Caminetti Law was passed in 1893, which provided for restricted hydraulic work under the direction and control of the California Debris Commission, composed of Army engineers.

There are large areas of gravels in California that could be worked by hydraulic methods, were it economically possible to operate. The present costs, however, including storage of debris, labor, and supplies, are entirely different from those that obtained in the 'Hydraulic Period," and the problem of restoring the gold yield of California hydraulic mines, though dark, has some rays of hope, and must be tackled as a new mining problem and not predicated on the practice of the days of 1860–1870.

The buried channels of the Forest Hill Divide, in Placer County, were first worked in a limited way in 1852–1853, and by 1866 drift mining was widely practiced and was a profitable method of gold-mining in many of the counties on the western slope of the Sierra Nevada traversed by the buried Tertiary rivers, so well described in various folios of the Geological Survey and by Mr. Lindgren in Professional Paper 73. Drift mining is still in progress, but with rising costs, particularly for timber and labor, many of the drift miners have been forced to cease operations. There are miles of unworked buried channels in California, many of which contain workable gravels, but here again each deposit must be treated as a new problem. It seems probable that many of these deposits will be worked at some future time.

The dredges, an Australian invention, changed and adapted to suit California conditions by a group of California and Montana

men, began their work in 1898, after a period of several years preparatory exploration and experimentation. The Feather River, near Oroville, was the first to have its gravels dug by these new machines. Ground on the Yuba, American, Bear, Mokelumne, Consumnes, and Merced rivers was rapidly acquired, and even the northern counties were not spared from the operations of the dredge men. During their life, 1898 to 1923, inclusive, the dredges have produced $95,720,000, a little over 5 per cent. of the total gold yield of the State. In 1910 there were 72 dredges in operation, the largest number in any single year. The annual yield of the dredges since 1906 has been from 5 to 8 million dollars a year. The dredge industry, however, faces extinction, for, though every effort has been made to find new ground, none of any consequence that can be profitably worked by dredging has been found in California. The present known areas of dredgeable gravels means a life variously estimated at from 8 to 12 years from the present. Probably 1935 will see the end of dredging in California, unless unforseen deposits or change of dredge design should make possible the digging of areas now impossible.

Quartz mines were first worked in the early 50's in Nevada, Tuolumne, and Mariposa counties. Their development was slow, for most of the men of the early days were placer miners. By 1883 there were, however, 2,000 stamps dropping in the State and treating 4,000 tons of ore a day. The dry gold quartz ores are the most widely distributed deposits in California, being found from the Oregon to the Mexican line. These are vein deposits in either metasedimentary rocks or in intrusives, largely granodiorite, which are presumably responsible for a large part of the gold mineralization.

As will be seen from the table, the mines producing dry gold ores have contributed over 57 per cent. of the total gold yield of the last 24 years, nearly twice as much as any of the other sources of gold in California. The chief sources of dry gold ores are the rich pocket type ore bodies, such as are found in the Alleghany district, Sierra County, the low grade pocket-carrying siliceous

ores of Grass Valley, Nevada County, and the stringer lode pocket-carrying deposits of the Mother Lode. Alleghany type deposits have so far not been proved to greater depths than 1,000 feet; the Grass Valley type are successfully worked at 6,000 feet, with every indication of continuance; and the Mother Lode type to depths of 5,000 feet, with no bottom in sight. The geologic experience on the Mother Lode is such that it would appear reasonable to reopen many of the mines which were supposed to have been bottomed near the 900–1,000 foot levels. There are also long stretches of the lode that are still worthy of surface and shallow prospecting.

In several localities in Shasta, Plumas, and the Foot Hill belt, pyritic copper deposits have been worked and, as will be seen by the table, have yielded about 2 per cent. of the gold produced in the last 24 years. There are also in the southern part of the State, bodies of contact metamorphic copper, which have been productive at various times, but are not now in operation. The copper-zinc ore bodies of the Shasta County belt are now being actively exploited, largely by reason of their zinc content, but the copper deposits are practically worked out, so far as commercially profitable ore is concerned. The Plumas County bornite-chalcopyrite copper ore bodies are at the stage of successful, active production. The Foot Hill copper belt is not being exploited as much as possible, but the ores carry little gold.

With the exception of some small lead deposits in Shasta County, all of the lead ores of the State are produced in the desert south and east of the Sierra Nevada mountains in what is geologically a continuation of the Great Basin Province. The ore deposits, chiefly valuable for lead-silver, lead-zinc-silver, zinc-silver, and copper-lead-silver ores, are closely associated with bodies of quartz monzonite type rocks intrusive into limestones and shales that are largely of Paleozoic age. The ore bodies are largely replacements in limestone. As will be seen from the table, the gold yield from this class of ore is insignificant and has not been plotted on the curve which accompanies this statement.

With an expanding market for zinc and the great scarcity of

lead mines throughout the world, the Southern California Desert should see a marked revival in mining.

While the curve of gold production shown in Fig. 1 has a downward trend since the early days of the war, when prices began to climb, there is nevertheless a hopeful feeling with regard to its future trend. With proper coöperative effort of geology, mining, money, and lack of adverse legislation, it should be possible to increase the gold yield from all classes of deep mines, but from the mines with dry gold ores particularly, and from the placer deposits which are susceptible of working by hydraulic and drift methods. It must be clearly recognized that dredge yield will undoubtedly decline from now on at a rapid rate. To maintain the relative gold curve at the rate for the last 10 to 12 years will necessitate the resumption of the deep-gold quartz, and hydraulic and drift mines.

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EDITORIAL

THE VALUE OF STATE GEOLOGICAL SURVEYS.

In a recent editorial article in this *Journal,* one of my editorial colleagues has discussed the value of and justification for the institution and maintenance of state geological surveys and the causes of success and failure of such surveys. He emphasizes that undoubtedly one of the chief objects in view in the minds of the legislators who provide the funds is the economic results that may come from the labors of the geologists.

Obviously, one of the fundamental factors required to enable a state survey to be successful, if success is to be judged by economic results, is the existence, within the territory to be surveyed, of some hitherto unused or undiscovered bodies of mineral of use to man. A state survey, if designed to cover too small an area, may be, from the economic point of view, foredoomed to failure, owing to the absence of such deposits of valuable minerals; and if such a state desire to retain a geological department, justification may have to be found in the higher reasons of education and civilization. In America, with its plenitude of universities, these phases of geology are usually otherwise provided for, so that in a state without a sufficiency of valuable mineral resources the operations of a state geological department are likely to come to an untimely end, *i.e.*, before the completion of the general geological map of the country that every civilized state should possess irrespective of other considerations.

For the discussion on its economic merits of this problem of the value of state geological surveys, it is necessary, therefore, to refer to surveys covering areas large enough for the economic phase of geology to be well represented. The United States Geological Survey and the Geological Survey of India are examples of geological survey departments operating over such large areas.

It may prove of interest to the reader to explain briefly what duties are undertaken by one of these departments, namely, the Geological Survey of India.

The Indian Empire is made up of British India and the Native States. British India is subdivided into provinces, each with its own Local Government and separate budget, of which the receipts are obtained partly by local taxation and partly by allotments from the budgets of the Central Government, the Government of India. The Native States are ruled by their hereditary chiefs and maintain political relations with the Government of India, either direct through officers of the Foreign and Political Department of the Government of India or through the agency of the Local Governments. Certain of the larger Native States maintain their own geological departments or geologists, Mysore being the most notable example. But, generally speaking, no provision for geological survey work is made either by the Native States or by the provincial or Local Governments in British India. The duty of providing for the geological survey of India as a whole is, in fact, undertaken by the Government of India, and the central department established for this purpose, known as the Geological Survey of India, has its headquarters in Calcutta, the former capital of India.

The prime reason for the maintenance of the Geological Survey of India is the encouragement of the development of the mineral resources of the country, and it has always been accepted that this object can be best attained by a regular systematic geological survey, having as its object the completion of the geological map of India. The desirability of such a service was early recognized in India, and the Geological Survey of India, which was founded in 1851, is, in fact, the fourth oldest of those still in existence, the older geological survey departments being those of Great Britain (1835), Canada (1842), and Spain (1849).[1]

To this centrally financed department is entrusted the geological

[1] It is recognized, of course, that geological work was financed officially by certain countries prior to this date without the complete organization of geological survey departments, *e.g.*, by France (1823), Massachusetts (1830), Belgium (1836), and Austria-Hungary (1849).

survey of the whole of the Indian Empire, but in cases where geological survey operations have been undertaken by Native States, we have, of course, left to the local geologists their own terrain. Otherwise, the Geological Survey of India works in all the provinces in British India and in the Native States, in the latter cases with the consent of the rulers, which is rarely withheld.

In addition to the principal work of preparing geological maps, special studies are made of deposits of minerals of economic value, advice is given to Local Governments, Native States, municipalities and railways, on engineering problems, such as sites for reservoirs and dams, the suitability of hill slopes *vis-à-vis* landslips, which are of frequent occurrence during the monsoon, and concerning earthquakes; advice is also given freely upon materials for building and road-making and upon the prospects of success of borings for water.

The minerals found in Native States are the property of the States, while in British India the mineral rights are exercised by Government, except in certain lands held on what is known as the permanent settlement. The conditions for the grant of prospecting licenses and mining leases in respect of minerals that are the property of Government are laid down in rules drawn up by the Government of India and administered by the Local Governments, to whom certain powers are delegated. If for any mining lease it is considered desirable to depart from the powers so delegated, the sanction of the Government of India, and in exceptional cases of the Secretary of State for India, is necessary. When the points under consideration involve technical issues, both the Local Governments and the Government of India often seek the advice of the Director of the Geological Survey of India, who thus exercises an important influence upon the mineral policy of the country.

The Geological Survey of India has also provided in the past for the educational side of geology by supplying lecturers to certain of the Indian colleges, and the department is now being closely identified with the foundation of a new institution at Dhanbad, financed by the Government of India, and called the Indian

School of Mines, the Director of the Geological Survey of India being *ex-officio* President of the Governing Body of the School.

I have now mentioned briefly the numerous ways in which a particular state geological survey—the Geological Survey of India—is of use to the country it serves, but I have not mentioned the financial aspect of the enterprise to the state.

This is not a place to enter into details, but the pioneers in India in the development of coal, oil, iron, manganese, chromite, copper, wolfram, and tin, for example, have recognized the large extent to which they are indebted to the work of this department, and it may be taken as a fact that many of the valuable mineral deposits of India were either discovered directly by the officers of the Geological Survey of India or as a direct result of the geological activities of the department. Accepting these facts, the financial benefit accruing to India from the activities of the Geological Survey in British India may be grouped under the three following main heads:

(1) Royalties on minerals, which are credited to Local Governments.
(2) Income tax receipts from mining companies, which are credited to the Government of India.
(3) Savings in the coal bill of the railway budget of the Government of India arising from the opening of railway collieries.

It is difficult to effect an exact allotment of credit for the receipts or savings under these three heads between the geological survey department and other workers, but it is easy to demonstrate that at a minimum the benefits due to the activities of the Geological Survey of India accruing now, and that will accrue for many years without any further work on the part of the department, amount annually to several times the annual charge for the maintenance of the department. In fact, one successful piece of work may pay for the upkeep of a state geological survey for a country.

It will be noticed above that whereas the whole cost of upkeep of the department is a debit against the Central Government, a

portion of benefits (royalties) goes to Local Governments. There is, however, a financial settlement between the Central and Local Governments, and it may be assumed that in this settlement due allowance has been made for this factor.

I have outlined above the wide scope that may be allowed to a geological survey department operating over a wide territory, and consequently the large benefits that may accrue to the state from its operations. The benefits so mentioned are mainly of a directly material nature, providing obvious justification for the maintenance of a state geological department. But there is also a higher aspect of the question. The efficient conduct of the operations of a geological survey department necessitates much work that appears at first sight to be of a purely scientific nature. In addition, work of obvious economic bearing frequently yields as a by-product results that are apparently of purely academic or scientific value. The advances to general knowledge that thus result are surely not amongst the least benefits to a country arising from the entertainment of a geological survey department, and in cases where the financial balance between the cost of maintenance of the department and the financial benefits received by the state appears to be on the debit side, the state could, probably with wisdom, regard the intangible benefits as sufficient to cancel this debit. In fact, the degree to which a state supports geological and other scientific departments may be taken as a measure of its enlightenment—that is, of its civilization.

L. L. FERMOR.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE CAMP BIRD COMPOUND "VEINDIKE."

Sir: Mr. J. E. Spurr in his interesting paper on the above subject in this journal (March–April, 1925) rejects a chemical explanation and relies on a purely physical one to account for precipitation of the gold in the vein quartz. The reason given (p. 126) for this is that ". . . The blocks in the andesite breccia, from top to bottom, are of the same andesite; and the andesite of the flow is also of the same kind." This may be quite true but Mr. Spurr has overlooked the point that the *available surface* is not the same in both cases, and that this is a very important distinction between the two rocks the sequel will attempt to show.

The andesite breccia is a clastic rock which though consolidated, is not homogeneous and the contacts of the fragments with one another and with the matrix form interfaces which provide potential channels (of varying size) for percolation of solutions. Such interfaces are lacking in the andesite flow. The *internal surface* of the breccia is thus enormously greater than that of the flow though both are formed of the same kind of igneous rock.

Mr. Spurr unknowingly emphasizes the importance of surface (as contrasted with mere porosity on which he relies) when, in describing (p. 117) the andesite breccia, he writes ". . . As seen underground the fragments are typically green, and the matrix is red, a striking contrast, showing that much of the fine material became oxidized during the process of expulsion and accumulation." Why was the matrix oxidized while the large fragments were not? Because the former possessed, in proportion to its mass, the necessary surface for reaction that was lacking in the latter.

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Before developing a chemical explanation for precipitation, it is interesting to examine Mr. Spurr's physical one. This is based essentially on the supposed "porosity" of the andesitic breccia permitting the escape of gases (unspecified) from the "ore magma" in the vein into the andesite breccia wall rock, this escape being attended by precipitation of gold in the vein.

The effect of the "porosity" is thus purely a volume one and contrasts with the surface explanation of precipitation to be advanced later.

The chief factors in Mr. Spurr's explanation consequently are: (1) The gaseous content of the "ore magma." (2) The porosity of the wall rock.

Of the nature of the gases supposed to be present in the "ore magma" Mr. Spurr says nothing but it is clear that he supposes some gases to be present in considerable quantity and to furnish "the magmatic gaseous tension pressure" to which he refers that is presumably equivalent to the preferable and more usual term total vapor pressure.

Waiving the debatable point as to the actual existence of an "ore magma," is the quantity of gas likely to be present in such, as large as Mr. Spurr implicitly supposes it to be?

The available evidence tends to show that of the gases present in an igneous magma (the cradle of the "ore magma") by far the greater part escapes in volcanic explosions and igneous intrusions, and that the gases present in the residual mother liquors or solutions (for which Mr. Spurr's "ore magma" is merely his own term) though no doubt chemically very active are present in only comparatively small amount. This relatively small quantity of "dissolved" gases in the ore magma would most probably consist of water vapour, carbon dioxide, sulphuretted hydrogen, fluorine and perhaps some others. From the nature and extent of the wall rock alteration and the mineralization of the main Camp Bird vein it is certain that only small amounts of carbon dioxide, sulphuretted hydrogen, and fluorine were present. This leaves "the magmatic gaseous tension pressure" (total vapour pressure) to be supplied almost entirely by water. Now, what

is the vapour pressure of water under the conditions likely to have existed at the time of vein formation and mineralization at Camp Bird?

Mr. Spurr supposes (p. 136) that at the time of deposition "... the top of the ore may have been 2,000 feet or more below the surface." From the nature of the mineralization and ore structures generally the Camp Bird vein belongs to the class of shallow zone deposits which Lindgren [1] regards as having been formed at depths which would include that supposed by Mr. Spurr for the Camp Bird and at temperatures ranging from 50° to 150° C. Accepting the upper limit in this case, viz. 150° (and thus giving the Camp Bird the full benefit of reasonable doubt on this matter) as that prevailing at the time of ore deposition, the corresponding vapour pressure of pure water is [2] barely 5 atmospheres and since the "ore magma" is supposedly a solution the vapor pressure (partial) of the water would be actually less.

From these considerations it can be seen that it is unlikely the "magmatic gaseous tension pressure" would be high.

With regard to the "porosity" of the wall rock, Mr. Spurr gives no information as to what he exactly implies in the condition of the andesitic breccia. His instructive account of the general geology of the Camp Bird locality as well as that of Ransome [3] concerning the district generally gives no ground for supposing large openings to exist in the rock so that its porosity must have been that of the kind due to pores, cracks, joints and other small openings ranging from sub-capillary to super-capillary in size.

From its mode of formation the andesite breccia must have contained connate water which during consolidation would, by flow or capillarity effectively occupy all the openings in the rock. There would thus be no empty spaces into which vapor could suddenly escape from the "ore magma" in its passage through the portion of the vein enclosed by the breccia.

[1] W. Lindgren, "Mineral Deposits," 1919, p. 205.

[2] Landolt-Börnstein, "Physikalisch-Chemische Tabellen," 1923, vol. II., p. 1319.

[3] F. L. Ransome, "Economic Geology of the Silverton Quadrangle, Col.," U. S. Geol. Survey, Bull. 182, 1901.

Rather would the gases of the "ore magma" slowly, by diffusion, possibly also by atmolysis, distribute themselves between the "ore magma" and the water or solution existing in the openings of the breccia according to their relative solubilities in each. Since gases, with the exception of water vapor, as has previously been pointed out, could only have been present in small quantity in the "ore magma" originally, the relief of total vapor pressure caused by their solution in the water of the breccia would only be very small.

So far as the water vapor is concerned, unless passage of the "ore magma" through the breccia were accompanied by a decrease in temperature there would be no change in its partial vapor pressure which as has also been previously indicated, must have constituted by far the greater part of "the magmatic gaseous tension pressure" (total vapor pressure) of the "ore magma." For the foregoing reasons it is submitted that the decrease of pressure assumed by Mr. Spurr to have taken place in the ore magma while enclosed in the breccia could not have occurred and the precipitation of the gold consequently could not have been due to decrease of "the magmatic gaseous tension pressure" as claimed by him.

The postulated decrease of pressure thus being unjustifiable mere porosity of the breccia is unlikely to have been a factor in precipitation. For, turning to a familiar example, is it the mere porosity of charcoal that makes it so efficient a precipitant of gold in the cyanide and chlorination processes or gives to that substance its well known decolorizing powers? If it be so then sand and gravel ought to be efficient precipitants and decolorizers too.

The efficiency of charcoal as a precipitant depends chiefly on a property of that substance much more fundamental than mere porosity, viz. on its enormous internal surface in proportion to its mass.

In the same way, on a smaller scale, the andesite breccia, owing to its clastic nature has a much larger internal surface than the andesite flow and the "precipitating power" of the former, it is submitted, was due to this.

The connate water, in contact with this internal surface of the breccia would, by reaction with the rock minerals and more particularly with those of the matrix already oxidized during deposition as described by Mr. Spurr, gradually by hydrolysis of silicates and other chemical action, accumulate in solution the more stable, soluble products of rock decomposition.

On the formation of the vein fissure and the advent of ore solutions some, at least, of the solutes present in the solution formed by the connate water, would be hypertonic (of higher osmotic pressure) with regard to the ore solutions and would consequently diffuse into the vein where, reacting with the ore solution, precipitation of the gold in the vein would follow either directly or indirectly.

Gold being so easily precipitatable by many different substances, it is not difficult to find a precipitant for it. Ferrous compounds would suffice or even the carbonates of calcium and magnesium as shown by Lenher.[4] Precipitation of the gold could also result from alteration of the general conditions of the ore solutions by the diffusion of those from the breccia.

If the gold were in the colloidal state it is also easy to account for its deposition in the vein by the influence of substances derived from the andesite breccia.

While osmotic pressure would determine the *direction* in which the diffusion of particular substances took place between the ore solutions in the vein and those in the breccia (and consequently also where reaction and precipitation occurred) the *rate* of precipitation would depend on the rate of diffusion which is specific and independent of osmotic pressure.

Mr. Spurr contrasts the deposition of ore in the wall rock at Porcupine and Cobalt with the absence of this at Camp Bird and the complete limitation of gold there to the vein itself. Elsewhere[5] the influence of wall rock on ore deposition having been discussed at length and the ability of osmotic pressure and dif-

[4] V. Lenher, ECONOMIC GEOLOGY, 13, 1918, pp. 161–184.

[5] H. C. Boydell, "The Rôle of Colloidal Solutions in the Formation of Mineral Deposits," *Bull. Institution of Mining and Metallurgy* (London), Dec. 1924, pp. 77–81.

fusion to adequately account for precipitation of gold either in the wall rock or in the vein generally and at Porcupine and Kirkland Lake in particular having been dealt with, there is no necessity to repeat the discussion here.

As outlined in the foregoing, by utilizing the internal surface of the breccia, its content of connate water, and the resulting solutions, together with osmotic pressure, there can readily be built up a chemical explanation for precipitation of gold in the Camp Bird vein which, resting on well established chemical and physical principles, requiring no assumption of the existence of an "ore magma" (other than the usual mineralizing solutions) or of its improbably high gas content possesses a much higher degree of probability than the crude and, as has been shown, highly improbable, physical explanation of Mr. Spurr.

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MAGNESITE DEPOSITS OF MANCHURIA.

Sir: In your issue of ECONOMIC GEOLOGY, Jan.–Feb., 1925, page 25, there appeared an interesting article on "The Magnesite Deposit of Manchuria" by Dr. Kunitaro Niinomy, who has recently given a lecture on the same subject at the Geological Survey of South Manchuria Railway Company here.

The important question involved is the origin of the extensive magnesite deposit, and whether it is a replacement of limestone or a chemical precipitation will have a great bearing upon the future investigation of similar magnesite deposits. As the writer is one of many who have seen the deposit, it is thought desirable to present a short comment on the subject.

According to Dr. Niinomy,[1] the magnesite deposit is lenticular in shape and occurs with dolomites, slates, and schists. "They (Magnesite deposits) grade into the latter rock (dolomite) at

[1] Niinomy, K., "The Magnesite Deposit of Manchuria," ECONOMIC GEOLOGY, Jan.–Feb., 1925, p. 41.

the ends and also at the side where the two are in contact, the only exception being at Pai-hu-shan, where a sharply defined lens occurs," and " there [2] is no evidence of bedding in the magnesite, but an indistinct banding is sometimes noticeable, due to the presence of streaks of graphite scales or plates." " There [3] is no distinct line of contact, either megascopically or microscopically between dolomites and magnesite, except at one locality, Pai-hu-shan."

The origin of the magnesite deposit is not distinctly stated, but in his recent lecture given at the Geological Survey of South Manchuria Railway Company here, he stated that although there are many possible explanations for the origin of the magnesite, he is more inclined to believe that an intrusive granite located at 15 kilometers northeast of the deposit may have supplied the magnesium solution, which replaced the calcareous portion of dolomites. Dr. Niinomy tabulates [4] several typical magnesite deposits of the world and points out in support of his conclusion that the Manchurian magnesite deposit is similar to these deposits with regards the origin of deposition because of the occurrence of similar metamorphic minerals. The occurrence of similar metamorphic minerals does not seem to have direct bearing upon the question of similarity in origin, excepting that their formation might be considered to be contemporaneous with the recrystallization of the magnesite.

The writer had an opportunity of visiting the deposit in 1916, and had come to believe it to be of primary sedimentary origin.[5] According to the writer's observation, the magnesite is bedded but not lenticular. Its length in proportion to thickness is so great and its thickness is so uniform for several miles with bedding planes parallel to those of the rocks above and below as to convince one that the deposit is bedded rather than lenticular.

[2] *Idem*, page 41.

[3] *Idem*, page 44.

[4] Niinomy, K., "The Magnesite Deposits of Manchuria," ECONOMIC GEOLOGY, Jan.–Feb., 1925, page 47.

[5] *Engineering and Mining Journal-Press*, Mch. 21, 1925, page 488, et al.

Of course the thickness differs slightly at many places, but this is not uncommon in any dynamically metamorphosed district.

If, as Dr. Niinomy observed, the gradation from the magnesite into the dolomite is anywhere shown, is it not a strong, if not the strongest, evidence of the replacement of calcareous rocks by the magnesian solution? It would be very instructive, if chemical analyses of the rocks in the affected zone be made showing gradational changes from dolomite to magnesite. It is to be regreted that the writer had not observed such gradational changes from dolomite to magnesite in the field at the time of his examination. Dr. Niinomy emphasized in his lecture that the absence of bedding structure in the magnesite bed testifies against the supposition that it is of primary sedimentary origin. On the contrary, it is more likely that it was chemically precipitated and later recrystallized, as evidenced by its saccharoidal texture. If it were of replacement product the magnesite should retain at least the original structure of the replaced sedimentary rock.

Further, the contact line between the magnesite bed and dolomites above or below is sharp and distinct. It is to be noted that the texture as well as color of the rocks above and below the magnesite bed is distinctly different from that of the magnesite. Doesn't such abrupt and distinct change from the surrounding rocks speak itself contrary to its being the product of replacement?

Dr. Niinomy ascribes the origin of the magnesite to the replacement of calcareous portion of dolomites by the magnesian solution leached out of the magnesium-bearing rocks under the influence of the granite intrusive. He has not shown, however, any microscopic evidence of the original and secondary crystals of magnesium carbonate in the replaced rock. Geologically how can one satisfactorily explain the occurrence of the extensive bedded magnesite with intervening beds of dolomites, slates, and schists? However strong the selective action of the magnesian solution may have been, it is inconceivable to assume that certain sedimentary rocks only could be replaced without even affecting other rocks in between.

As to the various theories of origin of magnesite a brief summary appears in The Data of Geo-chemistry.[6] Literature is not lacking with reports on sedimentary magnesite deposits. Mr. H. S. Gale [7] describes a sedimentary magnesite deposit near Bisnell, California. Chemical precipitation of magnesite has been recognized as one of the important processes by Mr. Frank W. Clarke.[8] And here in Manchuria all the field evidences strongly suggest that it was chemically precipitated and recrystallized later through regional metamorphism, for which the granite intrusion may have been responsible.

A question may now be raised as to the source of the great quantity of magnesium. Analyses of sedimentary and metamorphic rocks show that the older limestones are more highly magnesian than those of recent geologic periods, and those laid down since the Carboniferous are on the average but slightly dolomitic. At Ta-shih-chiao all the sedimentary and metamorphic rocks are magnesium-bearing, and dolomite is the most prevalent and extensive rock. Dr. Niinomy estimated that the district he studied is made up of 75 per cent. of dolomite, 12 per cent. of magnesite, and only 3 per cent. of limestone. It is plausible to assume, then, that the composition of sea water may have varied in geologic times, and it may have been more magnesian during the time when the deposition of the magnesite took place in the ancient Manchurian sea.

The conclusive geologic interpretation of origin of the Ta-shih-chiao magnesite deposit will have a great and important bearing upon the commercial development of the deposits, for if it were due to the particular acidic intrusive rock, as suggested by Dr. Niinomy, the peculiar characteristics of the granite should be thoroughly investigated, but if it were, as the writer firmly believes from the field evidence, due to primary chemical precipitation and later recrystallization, then the definite horizon of the magnesite beds in relation to other magnesium-bearing rocks

[6] U. S. G. S. Bulletin No. 695, p. 572.
[7] U. S. G. S. Bulletin No. 540, p. 483.
[8] U. S. G. S. Bulletin No. 695, p. 573.

should be made useful for further exploration of other similar deposits that may be found in Manchuria and China.

HIRONAO NISHIHARA.

DAIREN, MANCHURIA.

PROCESSES IN CONTACT METAMORPHISM.[1]

Sir: In an editorial in ECONOMIC GEOLOGY (vol. 20, pp. 687–690) Dr. Per Geijer raised some interesting questions dealing with the processes of contact metasomatism that are, indeed, difficult to answer if we are restricted to the invocation of gaseous solutions for the transport of the huge amounts of materials that take place in contact metasomatism. Dr. Geijer points out that while some deposits carrying considerable amounts of iron also carry fluorite many of the contact zones studied show little or no halogenides. Iron must then have been transported in some other way than as the volatile halogenides. In casting about for some other explanation for this transport of material he says:

> Certainly it is contrary to our established ideas of mineral deposition to imagine that iron can be carried as oxygen compounds in gaseous water solution.

It is no longer necessary, with our present knowledge of the behavior of solutions at high temperatures and pressures to call upon great quantities of volatile constituents for this stupendous shift of materials. The work of Smits,[2] Centnerswer,[3] Niggli[4] and Morey[5] has opened a great field in genetic mineralogy.

These workers have found there are two types of solutions at or above the critical temperature of water, those in which

[1] Published with the permission of the Secretary, Smithsonian Institution.

[2] A. Smits, *Zeitschr. f. Phys. Chem.*, vol. 51, p. 193, 1905; vol. 52, p. 497, 1905; vol. 54, p. 498, 1906; vol. 54, p. 512, 1906; vol. 67, p. 464, 1909; vol. 76, p. 445, 1911.

[3] M. Centnerswer, *Zeitschr. f. Phys. Chem.*, vol. 46, p. 427, 1903; vol. 61, p. 356, 1908.

[4] Paul Niggli, *Centr. f. Min. u. Geol.*, 1912, pp. 321–338, Niggli and Morey, *Jour. Am. Chem. Soc.*, vol. 35, p. 1086, 1913.

[5] G. W. Morey, *Jour. Am. Chem. Soc.*, vol. 39, p. 1174, 1917.

critical phenomena occur in saturated solutions and those in which critical phenomena do not occur. Magmatic solutions are of course saturated and there is now ample evidence to show that those solutions without critical phenomena are the usual type. The misconception most geologists apparently have is that the critical point of water has an influence on the existence of solutions at high temperatures and pressures and this point fixes the range beyond which liquid solutions cannot pass, above which solutions must be gaseous. Actually this is the case only where the concentration of the solute at the critical point is nil or nearly so. If the solute has an appreciable concentration at the critical temperature of water it effects an appreciable raising of the critical point. This may be made clearer if we consider the critical point as the maximum boiling point. The boiling point of water at 1 atmosphere pressure is 100° C. If 6.6 grams of NaCl is dissolved in 100 cc. of the water the boiling point is raised to 101° C. Likewise the critical point of pure water is 274° C. If at this temperature an appreciable concentration of solute is present the critical point of the solution is higher. For instance 4 per cent. of resorcin dissolved in liquid SO_2 raises its critical point 30°. In many solutions this raising can be carried upward until the triple point of the solute is reached. Those substances that have an appreciable vapor pressure at the critical temperature, that is the volatile substances, also have an appreciable solubility at this point. These substances are the so-called mineralizers. The concentration of the mineralizers in the solution is a function of their solubility and is only indirectly influenced by their volatility, and the critical temperature of water is entirely without influence on their solubility. One can readily see that the presence of abundant mineralizers does not necessarily mean gaseous solutions but rather they raise the critical point of the solution and hence favor the solutions in liquid form. The less volatile or involatile constituents can, of course, be carried in these solutions and it may be logically concluded that silica, iron and many other constituents have been introduced into the limestone contact zones by liquid solutions. The function, then, of

the mineralizers is not the transport of the iron, silica, etc., but to keep the aqueous solutions in liquid form at a temperature sufficiently high to give solute concentrations of appreciable magnitudes.

As yet we have precise data on only a few of the systems with which the mineralogist is particularly concerned. The system H_2O–K_2SiO_3–SiO_2 has been very thoroughly and painstakingly studied by Morey and Fenner.[6] Solutions in this system have been studied at temperatures above 1,000° C., far above the critical temperature of water and solution found to be continuous from the eutectic to the melting point of $K_2Si_2O_7$. The system $FeCl_3$–H_2O has also recently been studied.[7] This constitutes a study of one of the compounds most invoked as a mineralizer in the theory of contact metasomatism. This system, too, is of a continuous character.

In his communication, Dr. Geijer points out the great discrepancy between the amount of iron deposited in a contact zone with the amount of chlorine or fluorine found and that for one ton of magnetite formed through the agency of $FeCl_2$ or $FeCl_3$ sufficient chlorine must be set free for at least fourteen tons of scapolite. Certainly such relative amounts of iron and halogen bearing minerals are of rare and unusual occurrence. If, however, the iron can be carried without the aid of great amounts of mineralizers the problem becomes relatively simple. Let us say the iron is carried as the silicate, a not unlikely form in liquid solutions at high temperature and pressures. The formation of the contact minerals then would take place something according to the following relationship:

$$Fe_2(SiO_3)_3 + 3CaCO_3 = Ca_3Fe_2(SiO_4)_3 + 3CO_2$$

in which the end product would be andradite. The main bulk of the minerals in the contact zone can best be attributed to similar processes. It must again be emphasized that the mineralizers act as an agent to keep the solutions in a liquid state and not as the direct agent of transportation.

[6] *Jour. Am. Chem. Soc.*, 39, 1173, 1917.

[7] Ernst Stirnemann, *Neues Jahrb. f. Min.*, vol. 52, p. 334, 1925.

A discussion of all the features of high temperature and pressure solution is out of place here. The problem is a difficult one and the data are not entirely readily accessible to the geologist. An excellent discussion by Morey and Niggli however will be found in the *Journal American Chemical Society,* vol. 35, 1086, 1913 and by Niggli in *Centralblatt f. Mineralogie und Geologie,* pp. 321–338, 1912. The subject is thoroughly treated from a physical-chemical point of view and in less detail from a geologic point of view in Paul Niggli's book, "Die Leicht-flüchtigen Bestandteile im Magma." For a more complete understanding of the subject one must consult the original works of Smits.

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REVIEWS

Mineragraphy and Ore Deposition. By R. W. VAN DER VEEN, with an Introduction by J. F. KEMP. Pp. xv, 168, and 143 figures. Vol. 1. G. Naeff, The Hague, 1925.

The preface of this work is dated at Delft, December 1, 1924. On the 3d of April, 1925, there was announced the sudden death of the author as the result of an operation. It is to be hoped that the work only begun by the late writer will be continued by his associates. The book contains a portrait of Professor van der Veen and a short article to his memory by his assistant, Mr. C. Schouten.

Chapter I. includes a description of apparatus and the technique of procedure in grinding, polishing, and photographing the specimens. Chapter II. is given up to a brief discussion of the principles of the phase rule diagrams, eutectic and eutectoidic textures, and transformations in the solid state. These diagrams, which are taken from metallography, are used to discuss possibilities, rather than actualities, since comparatively few have been worked out for minerals, especially those that refer to transformations in the solid condition. Chapter III. is devoted to the identification of specimens.

The descriptive part of the book includes only the native semi-metals and the native metals, although in the discussion of the paragenesis of these many of the sulphide ore minerals are considered.

The author's method of grinding and polishing conforms very closely to the best American practice and may be outlined as follows:

1. A flat surface is obtained by grinding with carborundum powder mixed with water. This is done on an iron lap running 300 r.p.m.

2. The edges of the specimen are rounded off to prevent tearing of the cloth in later operations.

3. The grinding is continued by hand on a horizontal glass plate, using 60-minute carborundum powder.

4. Next the grinding takes place on a revolving copper or ebonite plate (1,400 r.p.m.), using 60-minute powder and water. This step is omitted with medium and soft ores.

5. Next the grinding takes place on a wheel like the one just mentioned, but moistened with diamantine powder and water. This finishes the operation for hard ores. The medium and soft minerals are still crossed by scratches.

6. The final polish (for the softer ores) is obtained by hand on a bit of ribbed membrane rubber 0.5 mm. thick stretched on a polished glass plate, using the finest alundum (No. 3. "Tonerde," Dejardin and Co., Düsseldorf).

6*a*. For bringing out very fine intergrowths and for photographs of etched surfaces a metal wheel with flannel is sometimes used.

In the investigation of polished surfaces hardness is determined by the use of needles of different metals, as brass, steel, copper, etc.; by rubbing the surface with powders of minerals of known hardness contained on soft pieces of wood; by relief; and by observing the character of the scratch secured in ordinary grinding, as it passes from one mineral to the next. For comparing the color of minerals a thin section of galena cemented to an object glass and placed on the polished surface may be used as a standard. A better method, according to the author, is to obtain coatings of "different metals and substances" on an object glass, scratching off a portion of the film, and placing it on the polished surface near the mineral to be compared. Directions for obtaining a silver film only are given. The color scale of Oswald used by Schneiderhöhn is not considered of much advantage. Internal reflection, color of powder, ease of obtaining a polish, and etching are other diagnostic features employed. Polarized light is found valuable (*a*) for distinguishing isotropic from anisotropic minerals, (*b*) for differentiating many anisotropic minerals from each other, (*c*) for observing fine intergrowths of minerals of nearly the same color, (*d*) for bringing out aggregate texture of anisotropic minerals without etching, and (*e*) for the observation of transparent and translucent minerals and their powders.

In the matter of fine intergrowths and some other fine textures, the author is strongly impressed with the principle of unmixing so thoroughly proved in some synthetic alloys, but still an uncertain factor in ore minerals. He says: "When we consider an unetched specimen of Sudbury ore, the pentlandite of this magmatic sulphide deposit seems to have penetrated later into veins and cracks through the pyrrhotite. When the pyrrhotite is etched, however, it appears that the pentlandite has accumulated on the boundaries of pyrrhotite grains, and that this has nothing to do with a later introduction of the pentlandite, but with a segregation or a transformation of a solution of both components." An intermediate stage as the result of more rapid cooling may show the pentlandite in part remaining in the pyrrhotite grains. In the discussion of the spots and laths of chalcopyrite in sphalerite the writer holds that the solid solution which cooled down rapidly does not show any arrangement of the chalcopyrite globules in the sphalerite crystal. These can be observed only with high power and appear as numerous globules "as if they were

suspended in an emulsion." In other specimens, where these inclusions are arranged according to cleavage lines in the blende crystals, the rate of cooling has been slower. When the rate of cooling has been still slower, the chalcopyrite is arranged outside the grain of sphalerite. Other intergrowths as the well-known bornite-chalcocite arrangement are also considered as the result of the breakdown of a solid solution. Furthermore, graphic patterns or mutual intergrowths may result from crystallization from "jellous mediæ."

In the discussion of the replacement of one mineral by another (metasomatism) the author cites as evidences:

(*a*) Attacked and corroded remains of idiomorphic crystals, although in magmatic deposits this texture may be the result of magmatic resorption.

(*b*) Veins of one mineral crossing another.

(*c*) Penetration of one mineral into another along cleavage lines or all sorts of cracks.

(*d*) Zonal texture of a crystal may sometimes point to substitution. In magmatic deposits it is the result of varying composition of the melt.

(*e*) Dendritic arrangement of mineral inclusions is also characteristic of metasomatism. In the discussion of the dendritic textures of the Cobalt (Ont.) ores, the author holds that the dendrites are formed along cleavage planes of calcite and dolomite. In case of perpendicular dendrites it is thought to be the result of deposition along the intersection of rhombohedral cleavage planes and the twinning plane of the negative rhombohedron, the solution attacking the carbonates along these lines.

In the Descriptive Part, which is followed by 130 most excellent photomicrographs, the native semi-metals and the native metals are taken up with reference to the following features: Blowpipe tests, polish, reflection, color, polarized light, etching, texture and crystal habit, and genesis.

The deposition of the native elements such as silver, copper, gold, and perhaps others in material formerly colloidal in nature is thought to be due to "electro-kinetic processes." To quote the author: "Probably the occurrence of extremely fine gold in kaolin is also due to the adsorption power of the colloidal kaolin material (Cerro del Guanaco, Chili) on gold solutions, which drop their gold ions when their electric charges are neutralized by the negatively charged kaolin." In the discussion of the deposition of native copper in limonitic material he further states: "The positive colloid $Fe(OH)_3$ does not adsorb the positive Cu ions, but when some negative manganese oxide colloids are present, these can be the cause of precipitation of Cu on limonite as well."

The appreciative introduction by Dr. Kemp contains a delicate tribute to the author for having written the book in English. This is a pleasant return for the compliment paid to American authors, "chiefly to whom

the merit is due for having pointed to the importance of metallographic investigation methods applied to minerals."

F. N. GUILD.

Elements of Geology. By T. T. QUIRKE. Henry Holt and Company, New York, 1925, 414 pp., 45 text figures, 102 half-tone illustrations.

This is a brief textbook, as the last 82 pages are taken up with appendices and the index. The book is designed to accompany a short course for students of Engineering and of Agriculture. It should be useful in any short college course concerned primarily with the physical aspect of geology. Less than 40 pages are devoted to historical geology. The value of such summary treatment may be questioned, but the author justifies this section of the book as affording a brief view of earth history not ordinarily available in the course of the technical student.

The subject matter of the book is arranged logically and under few headings. Part I. discusses the earth as a planet and describes the common materials in the crust. Part II. deals with geologic processes and is much the longest section of the book. Part III. contains the brief treatment of historical geology.

The appendices include outlines for fifteen laboratory exercises compiled by Harold R. Wanless. This combination of laboratory manual and textbook gives students engaged in laboratory work the advantage of ready reference to text materials. The exercises are ingeniously planned and arranged.

C. R. LONGWELL.

Outlines of the Occurrence and Geology of Petroleum. By I. A. STIGAND; with an appendix on "Geophysical Methods as Applied to Oil-finding," by M. MÜHLBERG. Charles Griffin and Co., London, 1925.

This book is a short treatise on petroleum geology, stated to be written chiefly for the benefit of the beginner or lay reader. It takes up briefly the subjects customarily discussed in works of this sort, such as available sources of supply, theories of origin, mode of occurrence, and the indications of petroleum. The outstanding feature of the book is an all too short account of the geophysical methods of oil exploration. However, a good bibliography of these methods is included for the benefit of those who wish to pursue the subject further.

PARKER D. TRASK.

Block Diagrams. By ARMIN KOHL LOBECK. John Wiley & Sons, 1924, vii, 206 pages.

In this valuable manual Professor Lobeck has set down in concise form full directions for the drawing of three-dimensional figures. While the book appeals primarily to the physiographer with its numerous chapters on the analysis and drawing of the various types of land forms, it should also be of use in general geologic illustration. It is to be hoped that this volume will encourage the replacement of the old two-dimensional cross-section by the more truthful and informative block figure. This type of illustration is also well adapted to the representation of mine workings and complicated structural relationships beneath the surface. A chapter describing a quick method for crystal drawing will be of interest to teachers of crystallography. The volume is fully illustrated and should prove widely useful in the field of geology.

RICHARD FOSTER FLINT.

An Introduction to Earth History. By H. W. SHIMER. Pp. 141, figs. 140. Ginn & Co., Boston, 1925. Price $3.00.

In the words of the author: "The volume is planned to serve as a point of view, a general survey to introduce the student to the more detailed knowledge of the earth that can be gained through chemistry, physics, astronomy, geology and biology." Evidently it is meant for college use.

The book is divided into three parts. Part I. deals with the cosmical history of the earth in 30 pages, in which are discussed concisely and clearly the subjects of matter, universe, and the origin of the earth.

In Part II. the geological history of the earth is considered under (*A*) forces which produce changes in the earth (127 pages), and (*B*) stratigraphic history of the earth (138 pages). The former treats of the atmosphere, streams, glaciers, oceans, forces within the earth, and geologic products of economic use. One is pleasantly surprised at the amount of material so excellently considered in a few pages, but its brevity is perhaps its fault. For a brief college course that would touch only the high spots of geologic processes, it is an excellent text, but it lacks body and detail for a larger and thorough elementary course. For example, the disintegration of rocks and formation of soils is covered in less than a page, and the entire subject of streams and stream work, including ground water and geysers, is covered in but 22 pages.

Part III. deals with the history of life on the earth and takes up in three chapters the history of plant life, of animal life, and a summary of both. The separation of these subjects from the stratigraphy is interesting and, I think, beneficial, for it presents a continuous picture of

animal life. However, their geologic setting is lost. One wonders also why the author devotes four pages to the evolution of the horse and none to the evolution of man. There is a hiatus between the paragraph on primates and the following one on anthropology.

The book is nicely gotten up. It is of convenient size, is clearly printed, and the illustrations are to the point. Above all, it is readable, and should be of interest to the layman as well as to the student. The material is up to date; even dinosaur eggs are included. One obtains a kaleidoscopic picture from the beginnings of the universe up to the present. It is educational, even if not adaptable for larger college courses.

ALAN M. BATEMAN.

Geology of the Netherlands East Indies. By A. H. BROUWER. Pp. 160. Graduate School Publications, Univ. of Michigan, Ann Arbor, Mich. Macmillan Co., 1925. Price $3.00.

Professor Brouwer of Delft University, Holland, while exchange professor at the University of Michigan, delivered a series of lectures on the above subject, and this book is a résumé of them. It deals with the relief figures of the islands, their historical geology, major tectonic features, volcanoes and earthquakes, and economic geology. The last chapter is the largest, and in 45 pages lists the metallic and non-metallic products. Chief attention is given to oil.

The book contains some interesting new thoughts on the larger structural features of this part of the Pacific, and contributes valuable information on volcanoes and earthquakes in that unstable region. The economic geology, with the exception of petroleum, has not been gone into extensively, and is largely a listing of the mineral products found there. The volume is well printed and contains many excellent plates.

A. M. B.

SOCIETY OF ECONOMIC GEOLOGISTS

The delegates of the Society of Economic Geologists to the International Geological Congress to be held in Madrid, Spain, in May follow: President H. Foster Bain, and Messrs. Alan M. Bateman, H. A. Brouwer, E. DeGolyer, Per Geijer, James F. Kemp, C. K. Leith, Waldemar Lindgren, R. A. F. Penrose, Jr., and Sidney Powers.

Dr. Per Geijer, of Djursholm, Sweden, has been appointed chairman of a committee to arrange for an informal meeting of the Society in connection with the International Geological Congress in Madrid next May. He wishes to state that this meeting will be devoted to discussions of Society affairs, and will be combined with a lunch or dinner, to afford an opportunity for the members coming from various countries to become personally acquainted with each other. In order to facilitate the preparation of this meeting and to be sure that every member who comes to Madrid will be informed when and where it will take place, members are requested to leave a note for the chairman of the committee, care of the International Geological Congress Bureau, when registering at this bureau, stating whether they wish to attend the meeting and the proposed dinner, and also whether they desire to bring up any subjects for discussion or otherwise have any special wishes regarding the meeting, and also giving their Madrid address. Dr. Geijer has appointed to date as members of his committee Professor A. H. Brouwer of Delft, Holland, Professor Alan Bateman of New Haven, Conn., and E. DeGolyer of New York City.

The 1926 Technical Meeting of the Society will be held in conjunction with the Geological Society of America at Madison, Wisconsin, in December, and there will be no meeting in New York this spring.

Frank L. Hess has been appointed one of the delegates of the Society to the Committee on Geology and Geography of the National Research Council.

Jan Versluys of Amsterdam, Holland, has been elected to membership in the Society.

SCIENTIFIC NOTES AND NEWS

Sidney Paige, of the U. S. Geological Survey, has accepted a position with the Amerada Corporation for work in South America.

J. Morrow Campbell has gone to Burma from London.

Fred Searls has gone on a trip to South Africa.

N. H. Darton has just completed his fortieth year on the U. S. Geological Survey. In service he is the senior among the active members of the staff of the geologic branch.

Albert O. Hayes, of the Canadian Geological Survey, is to be professor of geology at Lafayette College, Easton, Pa.

J. W. Beede, geologist for the Dixie Oil Company of West Texas, is president of the recently organized West Texas Geological Society.

Allen H. Rogers, of the firm of Rogers, Mayer & Ball, has returned to this country after four months in Chile and Bolivia.

Frederic H. Lahee, chief geologist of the Sun Oil Company of Dallas, Texas, left on February 22 for a five weeks' business trip to Venezuela.

Chester W. Washburne, who has been spending a year in Australia, will go to New Zealand for a year as chief geologist of the Taranaki Oil Company.

J. A. Newcombe, of Liverpool University and connected with the Royal School of Mines, is now on the staff of the University of Toronto.

George H. Garrey, mining geologist and engineer, is spending three months in Europe.

E. H. Sellards has been made associate director of the Bureau of Economic Geology of the University of Texas.

Walter S. Palmer, professor of metallurgy at the Mackay School of Mines, is spending three months in visiting various mining schools.

F. W. Maclennan, of the Miami Copper Company, is spending four months in Europe.

J. Mackintosh Bell, of Ontario, will return shortly from a trip to London.

B. Dunstan, chief government geologist of Brisbane, Queensland, estimates that the Mount Isa field has ore reserves to the value of twenty-one million pounds, and that the ore expectation is 20 million tons, also that the life of the field will probably be about one hundred years.

W. Spencer Hutchinson, who has lately returned from Africa, was present at the New York meeting of the Institute.

W. E. Scott, professor of geology and paleontology at Princeton University, is to be the recipient of the 1926 Hayden medal given by the Academy of Natural Science for notable work in research and investigation.

William Kennedy, aged 67, chief geologist of the Lone Star Gas Company, Dallas, Texas, for many years, died at Forth Worth on February 23, and was buried at Austin. Born in Scotland, he came to Texas in 1890; he was one of the pioneers on Gulf Coast salt domes after working on the geological surveys of Arkansas and Texas.

The American Institute of Mining and Metallurgy held its annual New York meeting February 15 to 18. Papers of interest in economic geology were: Magmas, Dikes, Veins and Contact Metamorphism, by Waldemar Lindgren; Geology of the Yoquivo, Chihuahua Mining District, by C. W. Hall; Geology and Ore Deposits of the Asientos Tepezala District, Aguascalientes, Mexico, by G. E. Anderson; Geology of the Zaruma Gold District of Ecuador, by Paul Billingsley; Lead and Zinc in Eastern Canada, by Frederick J. Alcock; Electrical and Electromagnetic Prospecting, by Hans Lundberg; Deposition and Enrichment at the Magma Mine, by M. M. Short and I. A. Ettlinger; Marcasite Inclusions in Fluorite from the Central Kentucky Barite-Fluorite Calcite Veins, by William D. Johnston, Jr.